AN ANALYSIS OF THE ECONOMIC VALUE OF IMPROVED FUELS AND FIRE BEHAVIOR INFORMATION

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AN ANALYSIS OF THE ECONOMIC VALUE OF IMPROVED FUELS AND FIRE BEHAVIOR INFORMATION

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EXECUTIVE SUMMARY

This report describes the development and case study application of a methodology for determining the economic value of improving wildland fuels information. The project was sponsored by the Fuels Inventory and Appraisal Group at the Rocky Mountain Forest and Range Experiment Station (RMFRES) of the U.S. Forest Service (USFS). The analysis was carried out jointly by staff from RMFRES, the Mt. Hood National Forest, and Decision Focus Incorporated. About five person-months of effort were involved.

The primary purpose of this work is to provide information and insight that will be of use in guiding the development of fuels appraisal systems by RMFRES staff. A secondary purpose is to provide a better understanding of the nature of fire and fuels management decisions and the relationship of fuels and fire behavior information to these decisions. It is hoped that insights gained through this analysis will be of use to fuels, fire, and land management staff throughout the USFS.

A wide range of decisions is based in part on estimates of forest fuels quantity, type, and condition. These decisions involve budget allocation and detailed planning for fuel treatment, presuppression activities, prevention efforts, and suppression strategy, as well as broader land management issues.

Presumably, better fuels and fire behavior information would enable national forest managers to make better decisions and thereby reduce fuel

treatment costs, fire management costs, and fire losses. Land management planners would make indirect use of such improved information when they balance the benefits of silviculture operations and recreation uses against anticipated fire losses.

Improving information on fuels and fire behavior can be costly. It is necessary to balance the economic value of such information with the costs of gathering or developing improved information. The value of new information depends upon many factors, the most important of which are the current level of information, the probability that new information will change decisions, and the reduction in costs or losses accompanying a decision change. This report describes a quantitative analysis of the economic value of improved fuels and fire behavior information and discusses the balancing of the economic value with the costs of such information.

The case study spans the range of decisions by addressing the value of fuels and fire behavior information in the context of two decisions:

1. The annual fire management budget decision made at the national forest level.
2. A site-specific fuel treatment decision.

In the analysis of each decision, the objective was to minimize management (or treatment) costs plus expected fire losses.

THE BUDGET DECISION

The specific decision analyzed was that of setting the budget level for prevention, detection, and presuppression activities at the national forest

level. Data used were representative of the Clackamas and Estacada districts of Mt. Hood National Forest. Alternatives evaluated involved incrementally increasing or decreasing the budget from current levels.

In setting the fire management budget, Mt. Hood forest managers face considerable uncertainty in fuel loading and characteristics. This study addresses the question, "What is it worth to reduce this uncertainty?" In order to to do this, a simple mathematical model was developed and used to evaluate fire losses plus management costs, given alternative budget levels and a range of settings of uncertain parameters. The model integrated information on the distribution of fuel load and types, ignitions, fire intensity, fire size, timber losses, and rehabilitation costs. Fuels information was defined in terms of the distribution of area best represented by each of the Northern Forest Fire Laboratory (NFFL) stylized fuel models. Mt. Hood fuels and fire management staff were uncertain as to what proportions of the total area should be assigned to each fuel model.

Through sensitivity analysis, the most critical uncertainties were identified as the distribution of fuel types and the intensities of fires that occurred in each fuel type. Probability distributions that reflected the state of information of Mt. Hood were encoded and incorporated in a decision tree. The decision tree structure was then used to analyze the economic value of reducing uncertainty in fuel types and fire behavior for a range of incremental budget change decisions.

BUDGET DECISION RESULTS

Over a wide range of cases, the expected value of perfect information on the distribution of fuel types was on the order of one cent per acre per

year, which corresponds to about $10,000 per year for the Mt. Hood National Forest. Note that this amount is the value of perfect information, that is, information that provides a complete elimination of uncertainty. As such it should be considered an upper bound on the value of new fuels information in the context of fire management budget decisions at the forest level. This suggests that any forest-wide fuels inventory effort would not be economically justified on the basis of fire management decisions. Funds invested in the development of an improved system of records-keeping (applicable to many national forests) to better utilize information already available (e.g., from timber stand surveys, fuel treatment activities, and other resource management activities) may be of greater net value.

The expected value of perfect information on fire intensity was typically in the range of one to five cents per acre per year. While this is probably insufficient to merit any forest-specific research or detailed data gathering, it could justify continued research in the development of improved models of fire behavior that would be of use in a number of forests.

A simple decision tree analysis was used to investigate the value of adding additional fuel models to the existing set, that is, of providing a set of stylized fuel models with greater resolution. An additional model only rarely resulted in a changed decision; as a result its availability had little value. This finding suggests that the resolution provided by sets of stylized fuel models now available is probably appropriate for fire management budget level decisions.

THE FUEL TREATMENT DECISION

A specific harvest site in the Clackamas district of the Mt. Hood National Forest was used as the basis for an analysis of a fuel treatment decision. Alternatives under consideration included no treatment, prescribed burning, and intensive mechanical and hand treatment. The key uncertainties were in the postharvest fuel load and in the intensity and effects of a prescribed burn.

The state of information of a Clackamas district fuels specialist on the postharvest load of fine fuels was encoded and represented by a probability distribution, which was combined with explicit assessments of uncertainty in weather and burn intensity to develop a decision tree model.

Critical outcomes included the post-treatment fire hazard and the costs of damage to white pine stands intended to provide for natural reseeding (costs include rehabilitation, hand planting, and delay in regeneration).

The fuel treatment decision was analyzed while parametrically varying four factors:

1. The range of intensities from a prescribed burn that results in acceptable fire effects.
2. The ability of a burn crew to compensate for nonoptimal weather conditions.
3. The post-treatment fire hazard costs.
4. The costs of fire damage to the white pine stands.

TREATMENT DECISION RESULTS

Results of the analysis showed that for a wide range of cases the no-treatment alternative was dominant, which leads to two possible conclusions:

1. Benefits of fuel treatment (such as for watershed, wildlife, or other resource values) are considerably in excess of those quantified in this analysis.

2. Much more treatment activity is being carried out than is economically justified.

If the first conclusion is correct and some type of treatment is to be carried out, the choice is between the prescribed burn alternative and the more costly but less uncertain intensive treatment. The expected value of perfect information on postharvest fuel load was evaluated in the context of this decision over a wide range of the four parameters previously listed.

Using the most likely scenarios, the expected value of perfect information on fuel load was approximately $300 to $800 for a 25-acre site (or $12 to $32 per acre). Information that could be expected to reduce uncertainty (perhaps reducing the variance of the probability distribution on the loading of fine fuels by 50-75%) would be worth $100 to $400. Accounting for all costs, this suggests that in many cases it would be worthwhile to invest one or two person-days in developing an improved estimate of postharvest fuel load <u>before</u> making the final treatment decision.

RECOMMENDATIONS

- Forest supervisors should consider forest-wide fuels inventory or fuels information management options which cost no more than one or two cents per acre annually.

- Continued research to provide better understanding of fire behavior and budget effectiveness (the relationship between fire management activities and fire losses) appears to be justified.

- More careful thought should be given to the no-fuel-treatment alternative following timber harvest. Expensive treatment does not seem justified in every case if fire management is the principal objective.

- For treatment decisions in which broadcast burning is likely to be a good alternative but for which significant resource values may be sensitive to over- or underburning, it is probably worth investing on the order of one person-day per 25-acre cut-block (or $10 to $30 per acre) in the improvement of the information base prior to making the final treatment decision.

Section 1

INTRODUCTION

This report describes a case study of the economic value of improved information about the quantity and properties of forest fuels. Presumably, better fuels information would enable national forest managers to reduce fuel treatment costs, fire suppression costs, and fire losses. The value of improved fuels information depends upon many factors, the most important of which are the current level of information, the probability that new information will change decisions, and the cost or loss reduction accompanying a decision change. This case study addresses these factors in a consistent fashion and estimates the maximum value of new fuels information on a dollar-per-acre basis.

The area chosen for this case study comprises two districts of the Mt. Hood National Forest, Clackamas and Estacada, covering about 400,000 acres of the western slope of the Cascade Mountain Range near Portland, Oregon. The areas are heavily forested with commercially valuable Douglas fir timber. About $6,000,000 worth of commercial saw logs are harvested from the units each year (600 acres). The fuel treatment and fire suppression budget for the units was about $750,000 in 1978, and wild fires burn an average of about 200 acres each year. The resulting fire losses average about $1200/acre or $240,000 for the planning units.

This analysis was conducted jointly by staff from three organizations: the Fuels Appraisal Group at the Rocky Mountain Forest and Range Experiment Station (RMFRES), the Mt. Hood National Forest, and Decision Focus Incorporated. Staff in the Fuels Appraisal Project at the RMFRES provided technical guidance and fire behavior modeling support. Several members of the Mt. Hood staff served as experts on local site conditions and fire management practices. Decision Focus was responsible for integrating information and conducting the analysis.

Managers at all levels within the Forest Service require some ability to estimate fire behavior and losses from fire. At the highest levels, land use policy is affected by fire hazards, as is fire protection planning, which is based on estimates of fire occurrence and behavior. At the lower levels, tactical fire suppression decisions and site-specific fuel treatment choices depend on fire behavior estimates. Fuels information plays a role in all these decisions to the extent that it affects the manager's ability to predict fire behavior and estimate fire losses.

This case study concentrated on determining the value of fuels information in the context of two clearly recognizable decisions:

1. The forest-level annual presuppression fire management budget-level decision.

2. A site-specific postharvest fuel treatment decision.

For each of these decisions, a substantial amount of money is allocated annually, and the stated purpose of the expenditures is to reduce fire losses. The alternatives, outcome measures, and major uncertainties for each decision are summarized in Table 1-1.

Table 1-1

SUMMARY OF DECISIONS ADDRESSED IN THIS STUDY

	Decision Alternatives	Outcome Measures	Major Uncertainties
Annual Fire Management Budget Decision	Continue current budget level Increase budget Decrease budget	Fire management costs Fire losses(resource value losses from wildfires)	Aggregate fuel load characteristics Fire intensitities given fuel load Budget effectiveness
Fuel Treatment Decision	No treatment Prescribed burn YUM 6x6*	Post-treatment fire hazard Losses to white pine stands	Postharvest fuel load Prescribed fire intensity Treatment effects (fuel reduction and damage to white pine)

*YUM 6x6 stands for Yarding Unmerchantable Material--all material exceeding 6 feet long by 6 inches in diameter.

Fuels information is used in the budget decision to estimate the seriousness of the fire hazard and the potential effectiveness of money spent preventing and managing fires. Presumably, the budget will be too small if the expected fire hazard is underestimated and too large if overestimated. Fuels information is used in the site-specific fuel treatment decision to estimate the effects of a prescribed fire as well as the hazards associated with different treatments.

These two decision classes span the range of fuel related fund allocation at the forest level. While the budget decision is large, it is made only once a year. The annual budget for fire prevention, presuppression, and initial attack was about $266,000 in 1978 for the Clackamas and Estacada planning units. (An additional $477,000 was budgeted for treating the fuel associated with current and past logging operations. The bulk of these latter funds is from the timber sale collections.)

The site-specific fuel treatment decision is relatively much smaller and involves expenditures of from $2,500 to $32,500, depending upon the treatment chosen. However, roughly 25 fuel treatment decisions of this type are made each year within the Clackamas and Estacada planning units. The relative size and frequency of these decisions is illustrated in Figure 1-1.

A third decision class, the makeup and level of initial attack forces, was also studied. After a preliminary working session with Mt. Hood Forest staff, it was concluded that improvement in fuels information by itself would have little or no impact on the way initial attack forces are

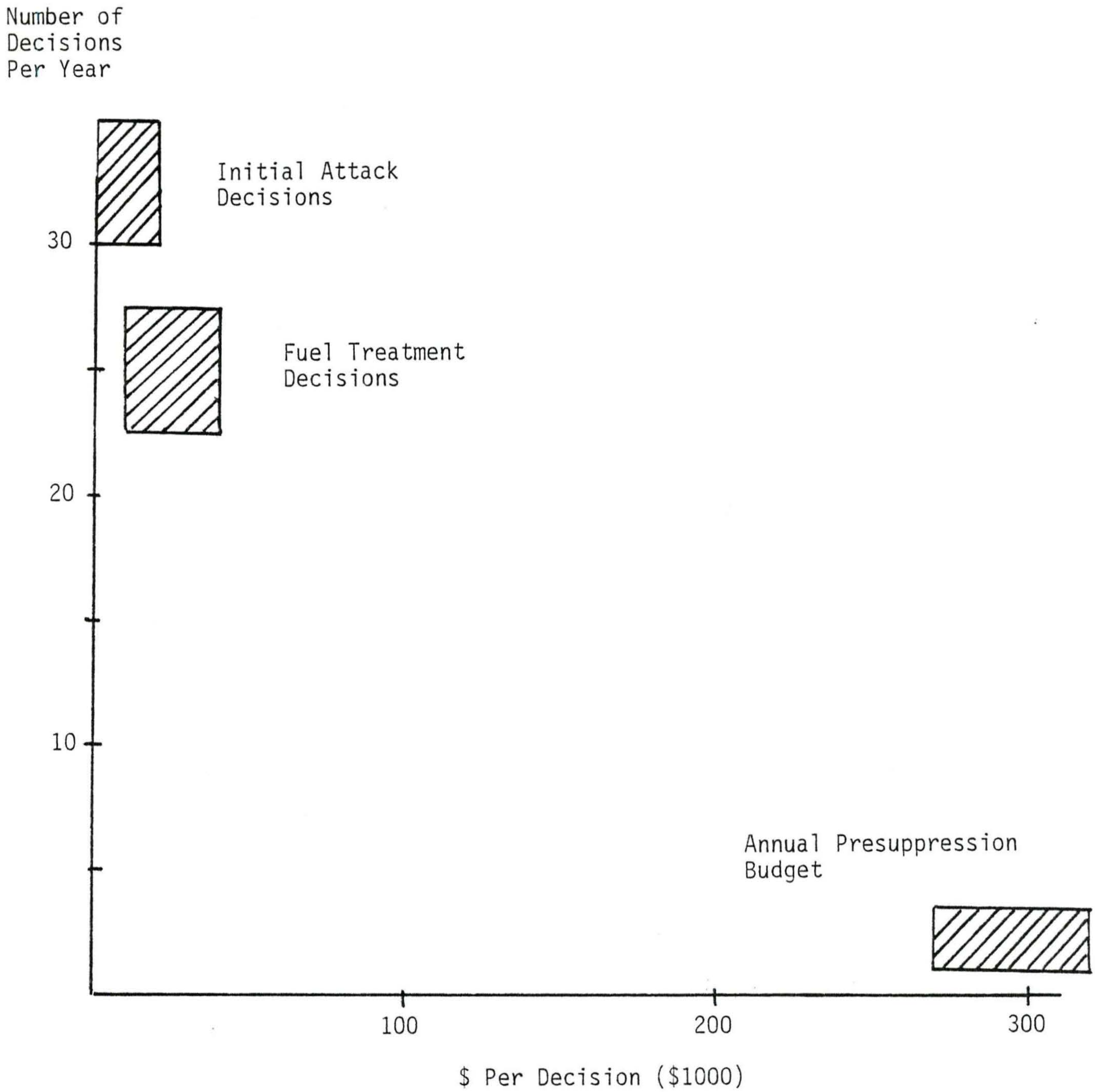


Figure 1-1 RELATIVE SIZE AND FREQUENCY OF DECISIONS ADDRESSED IN THIS STUDY

designed. A description of the process that led to that conclusion is contained in Appendix B.

The remainder of this report is organized as follows. Section 2 contains a tutorial explanation of how the economic value of information can be determined in the context of a decision. Section 3 describes the modeling and analysis associated with the budget decision. An analysis of the site-specific fuel treatment decision is contained in Section 4. The authors reiterate at this point that the object of this report is to provide insight into the role of fuels information in these decisions and its approximate value and not to derive a precise single number that expresses the value of additional fuels information.

Section 2

TECHNICAL APPROACH

The economic value of fuels information is calculated by estimating the impact that improved information has on fire losses and management costs. This section contains an overview of the forest level budget decision and how it might be affected by fuels information. An illustrative calculation of the value of perfect information is also included in this section to provide an understanding of how the economic value of information is calculated. Actual calculations for the Mt. Hood case study are discussed in Sections 3 and 4.

Ideally, the budget is set at a level that minimizes management costs plus fire losses (losses include wildlife, watershed, and recreation values, as well as timber values). The optimal budget level is illustrated in Figure 2-1. Choosing the optimal budget would be straightforward if the relationship between losses and presuppression expenditures were known as indicated in the figure. The budget decision is complicated, however, by the fact that the budget/loss relationship is highly uncertain. The major contributors to this uncertainty are the number and location of fires in the coming year, fuel conditions, weather, fire behavior, fire effects, and the effectiveness of presuppression expenditures.

The object of this case study is to estimate the economic value of reducing just one of the uncertainties, specifically, fuel conditions.

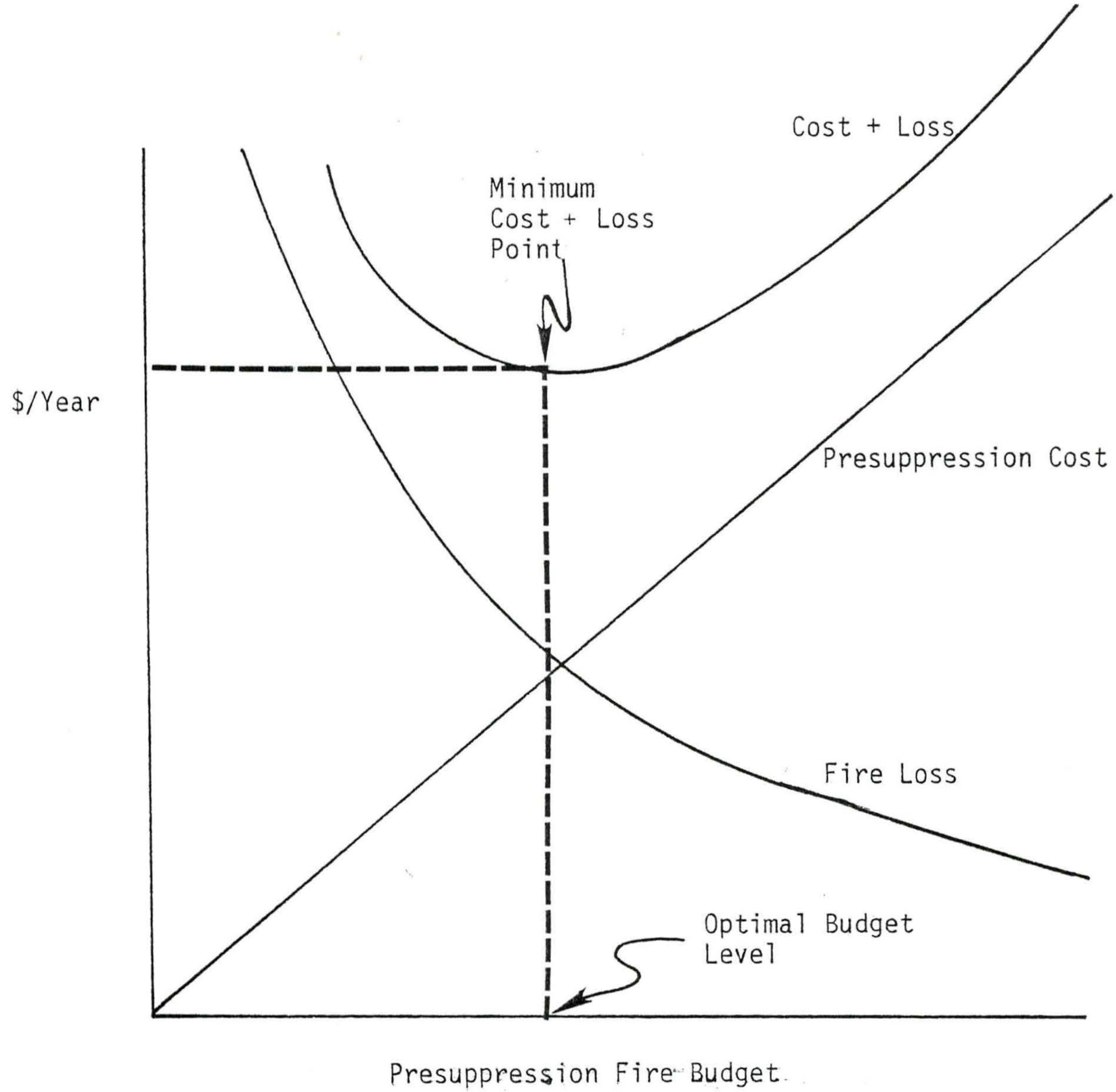


Figure 2-1

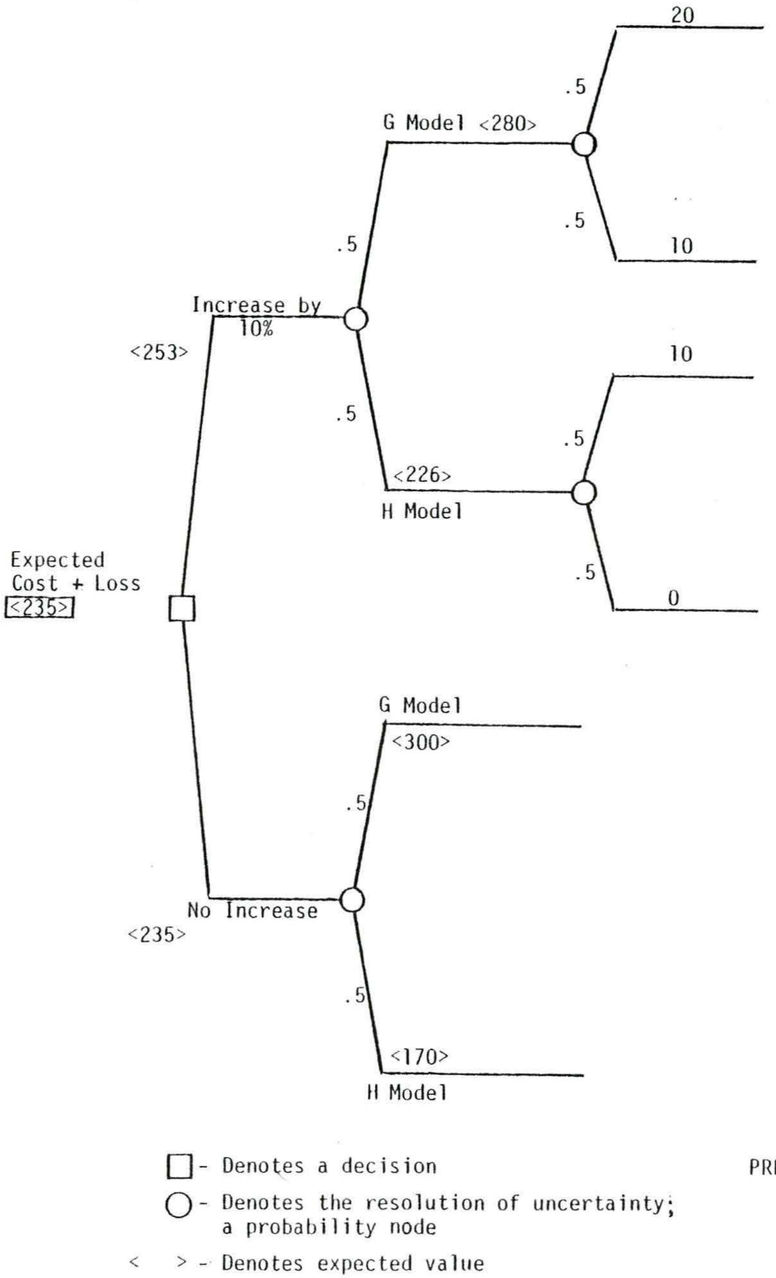
DETERMINATION OF THE OPTIMAL BUDGET LEVEL

To illustrate the methodology, suppose that the only uncertainties are fuel loading and control effectiveness. Suppose, also, that the budget decision is simplified to two distinct alternatives: increase the budget by 10% or maintain the current level. This decision, the subsequent uncertainties, and the outcomes (cost plus loss) are diagrammed in decision tree form in Figure 2-2. As indicated in the diagram, there are two possible fuel-loading levels: 100% of the area is equivalent to a G fuel model or 100% of the area is equal to an H model.* Assume that the entire area (forest or planning unit) is covered with the same fuel bed and that there is a probability of 0.5 that the fuel is described by a G fuel model and a 0.5 probability that it is described by an H fuel model. If the increase-budget alternative is selected and the G model turns out to be most representative of the fuel, there is an equal chance that the budget increase will result in a 10% or 20% reduction in the number of escaped fires. For the same alternative, the H model implies an equal probability of a 10% decrease or no change in escape fires.

Hypothetical outcome costs are broken down into three classes--presuppression, suppression, and resource losses--and are itemized at the tip of each branch. Suppression costs are proportional to resource losses.

Tracing one path through the tree for exposition, the upper path denotes a choice to increase the budget by 10%, the fuel bed is most closely characterized by a G model, and the effect of the 10% budget

* National Forest Fire Laboratory stylized fuel models: H model implies a fuel loading of about 15 tons/acre (fine fuels), while the G model represents a loading of about 30 tons/acre.



Presuppression Budget	Fuel Loading	Effect of 10% Budget Increase (% Reduction in Escaped Fires)	Probability of This Outcome	Presuppression Costs ($1000)	Suppression Costs ($1000)	Resource Losses ($1000)	Total Cost + Loss ($1000)
Increase by 10%	G Model	20	.25	$110	$40	$120	$270
Increase by 10%	G Model	10	.25	110	45	135	290
Increase by 10%	H Model	10	.25	110	18	45	173
Increase by 10%	H Model	0	.25	110	20	50	280
No Increase	G Model		.5	100	50	150	300
No Increase	H Model		.5	100	20	50	170

FIGURE 2-2

PRESUPPRESSION BUDGET DECISION

increase is a 20% reduction in escaped fires. This scenario results in $110,000 in presuppression costs, $40,000 in suppression costs, and resource losses of $120,000.

Given the uncertainty and cost structure of the example, the expected cost plus loss is greater for the increased budget option--$253,000 versus $235,000 for the no-increase option. (The term "expected cost plus loss" is used here in the statistical sense. It is the sum of the probability of each outcome times its cost; e.g., 235 = 0.5 x 300 + 0.5 x 170.) Assuming that the expected value is the basis for the decision, the no-budget-increase alternative is preferred in this example.

What would it be worth to know precisely whether the fuel bed is G or H before making the budget decision? In other words, how much should we be willing to pay a clairvoyant to look into a crystal ball and tell us which fuel model is appropriate? By a simple example, we can calculate the expected value of the information by rearranging the tree to represent the sequence of events when fuels information is known before the decision is made. This situation is diagrammed in Figure 2-3. The G model probability is still 0.5 from our perspective, but at the time the decision is made, it is either 1 or 0, depending on whether the clairvoyant says "G" or "H." If the clairvoyant says that the G model is appropriate, we would change our choice and increase the budget, because under these circumstances the expected cost plus loss is lower ($280,000 rather than $300,000) if the budget is increased. If we knew for sure that the H model were appropriate, we would not increase the budget but would stay with the same

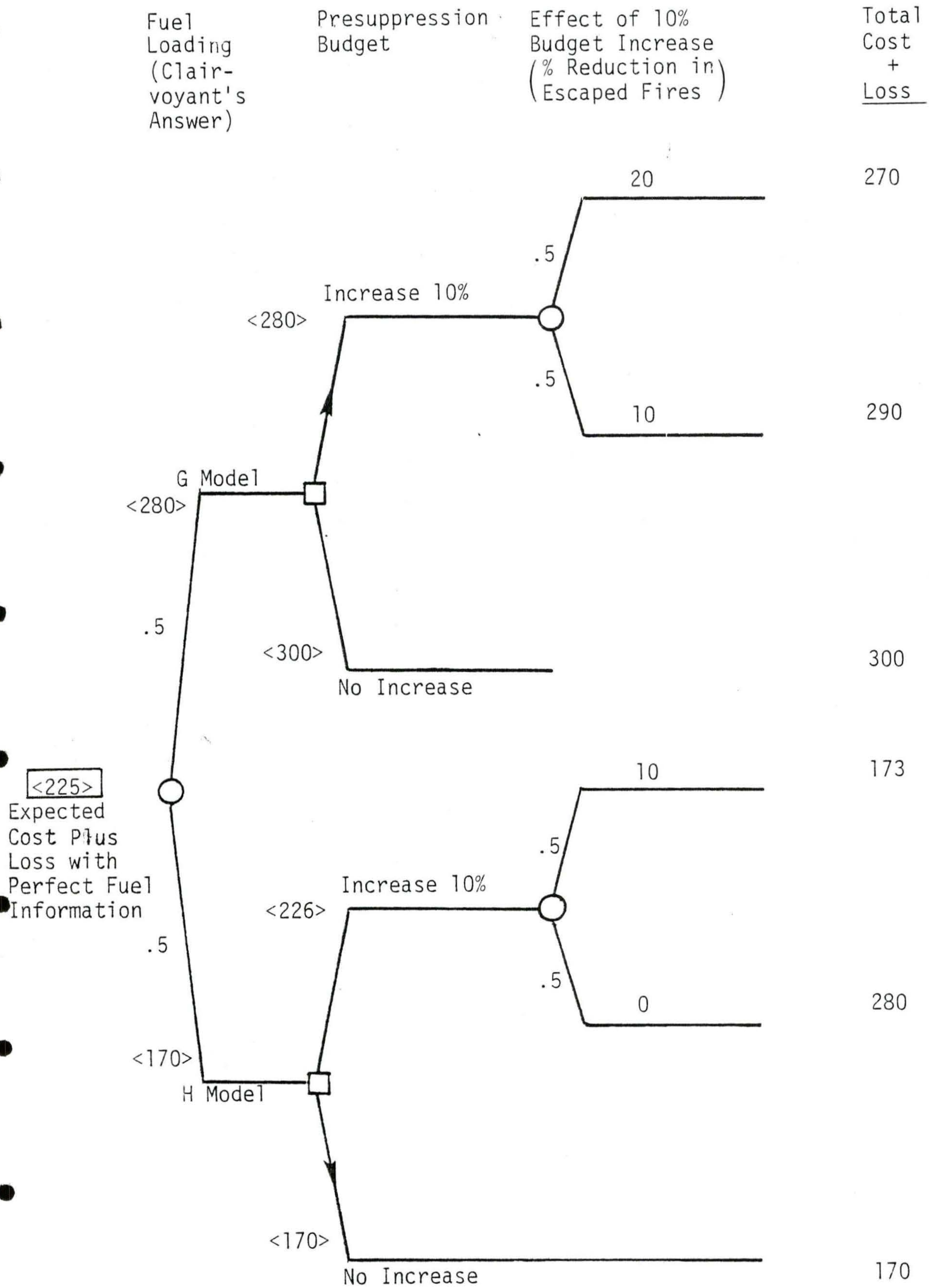


Figure 2-3

CALCULATION OF EXPECTED COST PLUS LOSS WITH PERFECT FUEL INFORMATION

alternative. The expected cost is then $170,000. The arrows in the diagram denote the lowest cost alternative at each decision node.

We should be willing to pay an amount equal to $10,000 for perfect information on fuel conditions before making the budget decision. This amount is the difference between the expected cost with prior information from Figure 2-2 ($235,000) and the expected cost with perfect information from Figure 2-3.

Another way of looking at this is illustrated in Figure 2-4. Here the tree is redrawn to make it apparent that the expected cost savings results from the clarivoyant's perfect information. Briefly, if the clairvoyant says "G," our choice is changed from no increase to increase 10% and the resulting expected savings are $20,000 (300 - 280). If the clairvoyant says "H," the decision does not change and the expected cost plus loss is unchanged. The probability that the clairvoyant will say "G" and save us $20,000 is 0.5; therefore, the expected savings is 0.5 times $20,000 or $10,000 which matches the previous value of perfect information calculation. For further discussion of this procedure, refer to references [1,2].

Although perfect information is not attainable in practice, the expected value of perfect information is useful because it provides an upper bound on what one is willing to pay for any level of fuels information in the context of a single decision or class of decisions. The perfect information concepts are used in the following sections to provide insight into the value of fuel inventory or modeling efforts. The value of information is estimated under a broad range of conditions to provide a test of the robustness of the estimates.

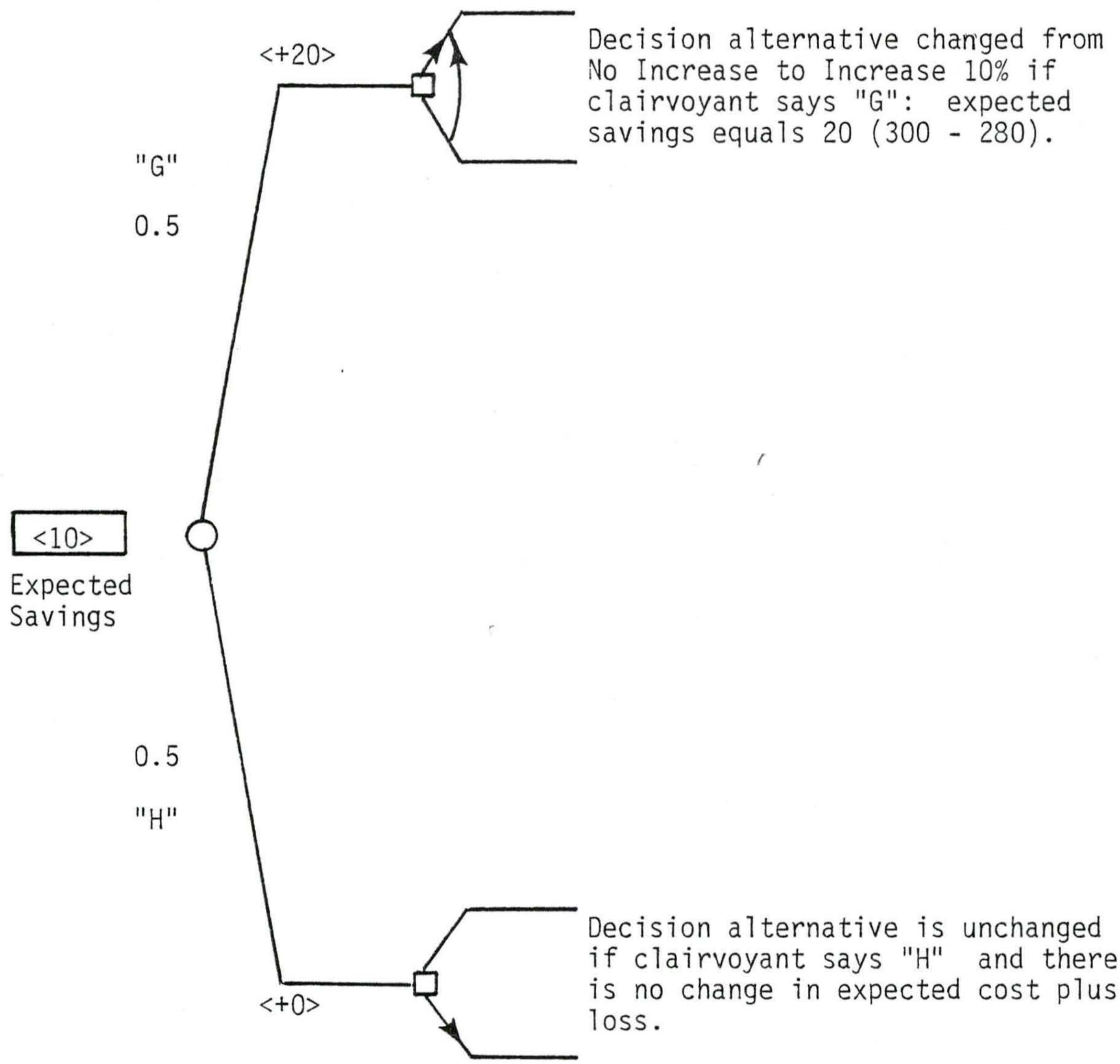


Figure 2-4

CALCULATION OF EXPECTED SAVINGS FROM PERFECT INFORMATION

Section 3

THE BUDGET DECISION

This section examines in detail the decision made by the management of a national forest in setting a budget level for fire management activities. The specific decision evaluated in this section of the case study is the overall fire management budget level for the Clackamas and Estacada districts of the Mt. Hood National Forest. Some insights were also gained into the allocation of the overall budget among the various fire management activities. Although the details reflect these two districts, most of the insights and conclusions are applicable to the entire Mt. Hood National Forest and, in fact, to many national forests.

The section begins with a discussion and definition of the budget decision, including identification of the factors under control of the decision makers, definition of important outcomes, and characterization of important uncertain factors. The mathematical model used to evaluate fire losses plus management costs, given alternative budget levels and various settings of uncertain parameters, is discussed. Extensive sensitivity analyses, carried out by using the model, are summarized; and some insights gained are discussed. The results of a detailed analysis of the economic value of fuels and fire behavior information are presented. A summary and review of important insights and recommendations completes the section.

THE DECISION

Nature of the Decision

The management of every national forest must determine its annual budget request for fire management activities. The fire management budget for a national forest includes funds allocated to activities, including prevention, detection, presuppression, maintenance of initial attack and air support forces, and fuels treatment. Suppression costs have generally been accounted for separately, although this approach may be altered in future planning and budgeting. Decisions must also be made regarding the breakdown of the budget among the various activities. The budget request is reviewed and frequently modified at the regional and national levels of the U.S. Forest Service (USFS) and, ultimately, by Congress. This case study will concentrate on the decision made by the individual national forest staff about its optimal level of fire management expenditure.

Definition of Outcomes

Section 2 introduced the cost-plus-loss criterion for determining the optimal budget level; the objective is to minimize the sum of fire management costs and losses caused by the fires and fire-associated activities. If the relationship between fire budget and fire losses were well known, that is, if there were virtually no uncertainty, it would be relatively easy to identify the optimal budget level. The relationship, however, is not only complex but highly uncertain because of such factors as the number and location of ignitions, fuel loading and characteristics, weather, fire effects, and effectiveness of fire management activities.

The cost side is reasonably clear. For a given year, uncertainty is introduced only by the possible range of expenditures for fire suppression. The losses are more difficult to determine. Most easily measured are the value of lost timber and costs of rehabilitation. The losses may also include watershed, recreation potential, visual amenities, and other resource values. The fact that these losses are often difficult to measure and equally difficult to put into economic terms does not obviate the necessity for considering them when analyzing forest management decisions.

One way to represent the decision is outlined in Figure 3-1: the decision itself is shown at the bottom of the figure; important uncertainties are shown at the left. The decision alternative selected, the uncertain factors, and the forest system interact to result in a set of outcomes, which are the factors a decision maker would like to know to evaluate the consequences of the decision. The outcomes are assigned values and are added with the management costs to produce a net cost plus loss.

Representation of Uncertain Factors

Preliminary sensitivity analysis identified fuel loading and the resulting fire behavior as the most critical uncertain factors affecting the budget level decision. While uncertainty in fire effects and resource values was important, these elements were treated parametrically. Uncertainty of budget expenditure effectiveness was also important and was treated separately. (Effectiveness is measured as the reduction in fire losses associated with an increase in the budget.) Part of the uncertainty in fire intensity reflects weather variations. Spacial variations in

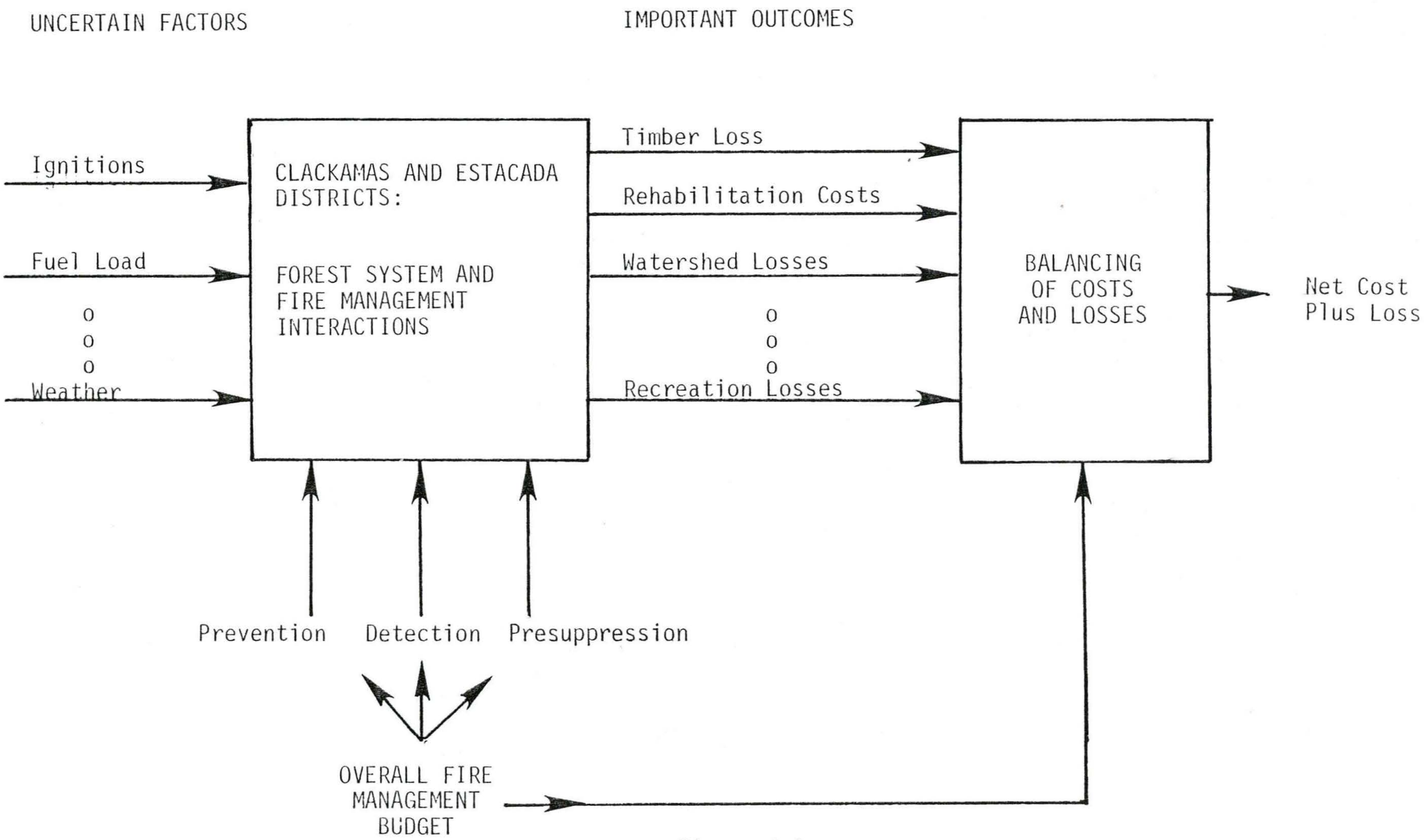


Figure 3-1

BUDGET DECISION OUTLINE

weather data and uncertainty in the number of ignitions tended to average out and merited less detailed analysis.

<u>Fuel Loading</u>. For a decision at the aggregate level of the overall fire management budget, the stylized fuel models developed by the Northern Forest Fire Laboratory (NFFL) were used as a starting point to represent fuel loading and characteristics. A simple analysis, described later in this section, was used to investigate the value of developing a more detailed set of stylized fuel models (e.g., more models, thus providing greater resolution). Mt. Hood fuels and fire management staff felt that four of the NFFL models will adequately describe the fuels conditions of the Clackamas and Estacada districts. These were the G (timber litter and understory), H (timber litter), I (heavy slash), and J (medium slash) models. Fuel and fire managers on the Mt. Hood National Forest staff were uncertain as to how the total area should be allocated to the four stylized models. The uncertainty was reflected in varying estimates by Mt. Hood staff of the fraction of the total case study area that should be represented by each fuel model. For example, the estimated area to be represented by the slash models (I and J) ranged from 5 to 30% of the total.* Note that some of this uncertainty is due to the approximate nature of the stylized fuel models. A typical uncertainty was whether to represent an area with brush, some old slash, and partial timber as a J type or a G type. A working paper prepared earlier in the fuels

*The range of uncertainty is defined explicitly later in this section (see Figure 3-5).

information project discusses in more abstract terms some of the implications of using stylized fuel models and provides some insights into when it may be more appropriate to use direct assessment of fuel loading rather than stylized models [3].

Fire Behavior. For this analysis, fire behavior was represented by the fireline intensity and size of the fires. Intensities used were calculated by Ft. Collins staff using the FIREBEHAV system, which integrates fire weather station records and stylized fuel models with the Rothermel/Albini fire behavior model [4,5] to generate a cumulative probability distribution for fireline intensity. The uncertainty represented by the cumulative distribution reflects weather variations. Runs were made for each fire weather station in or adjacent to the Clackamas and Estacada districts and for each stylized fuel model appropriate to the area. (A sample run is included in Appendix A.) The distributions for the several fire weather stations were averaged to produce a single probability distribution for each stylized fuel model. Discretized versions of these distributions are listed in Appendix A.

An additional source of uncertainty is introduced by the necessarily approximate nature of the fire behavior model itself. The representation of this uncertainty is discussed later in this section (see Figure 3-6 and associated text).

Fire sizes were broken down into four categories: 0-1 acres, 1-20 acres, 20-200 acres, and greater than 200 acres. This breakdown corresponds in a rough sense to the following grouping of fire size classes

used in the 5100-29 fire reports data base: A and B, C, D and E, and F and G. Even when one can assume that a particular fuel model is applicable and when weather conditions are known, there is still considerable uncertainty as to the size of a fire. This is due to the actual spacial variations in fuel load and characteristics, topography, and other factors. Uncertainty in fire size and intensity and other factors were encoded during a series of interviews and discussions with Mt. Hood staff and will be discussed later.

Decision Tree Representation

Figure 3-2 shows a generalized decision tree representation of the fire management budget decision and important uncertain factors. The boxes represent decisions, and the lines emanating from a box represent decision alternatives. In this tree the decision and uncertainty, or chance, nodes are not connected. This convention is a shorthand representation of the tree where each node is connected to all branches of the preceding node. The square node represents the decision, while the circle nodes represent the uncertain variables.

THE COST-PLUS-LOSS MODEL

A simple quantitative model was developed to calculate fire management cost plus fire losses under various assumptions. The model is intended to provide a consistent framework for comparing alternatives and analyzing sensitivities; its results should not be interpreted as precise predictions.

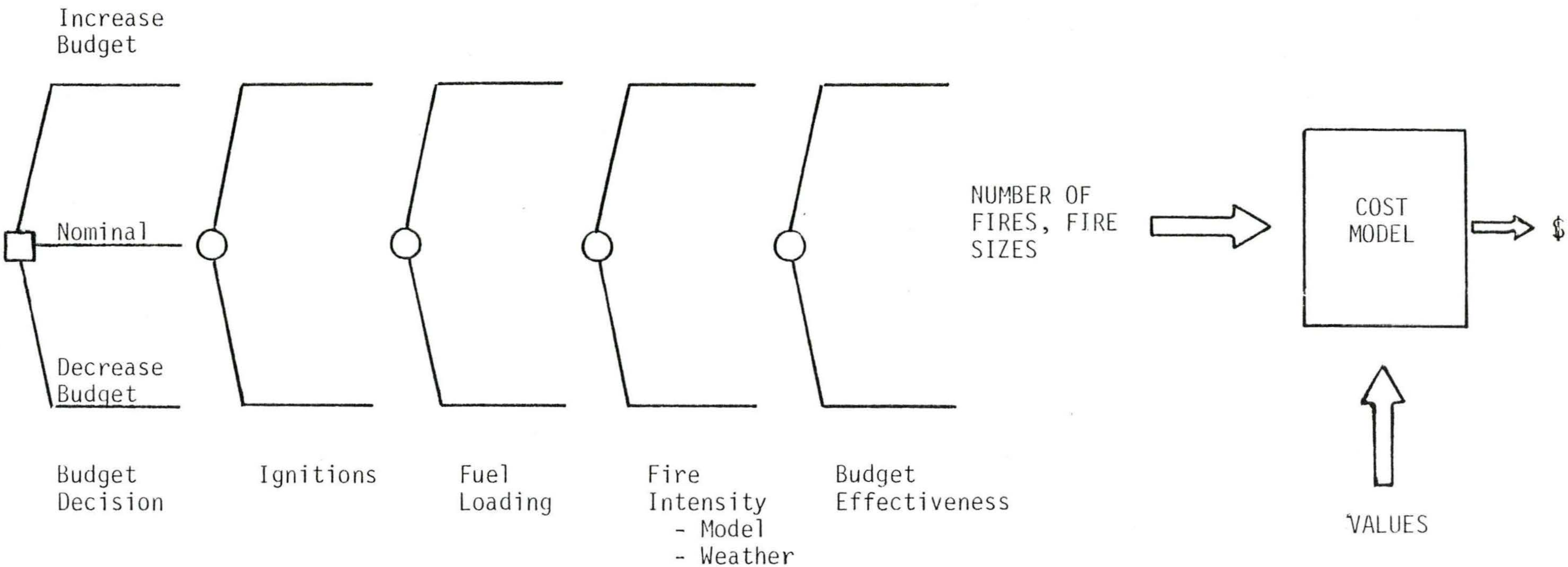


Figure 3-2

GENERALIZED DECISION TREE FOR BUDGET DECISION

Overall Model Structure

The model is composed of a number of submodels, as shown in the block diagram of Figure 3-3. The ignitions submodel divides ignitions into three classes by cause: industrial, other human-caused, and lightning. The nominal or long-run expected number of ignitions in each class is adjusted to reflect changes in prevention activities.* The breakdown of annual ignitions used for most model runs (reflecting long-term averages based on 5100-29 individual fire report data, adjusted for recent prevention activities) consisted of 1 industrial ignition, 25 other human-caused ignitions, and 8 ignitions caused by lightning.

The fuels submodel reflects the allocation of the total area (in this case, of the Clackamas and Estacada districts) to the appropriate stylized fuel models. The breakdown drives the fire location submodel. The nominal assignment of area to the fuel models was 280,000 acres to the G fuel model, 80,000 acres to the H model, and 20,000 acres each to the I and J models. These values are the medians of the estimates provided by Mt. Hood staff.

The fire location submodel assigns ignitions to area types (each area type being represented by a stylized fuel model). All industrial ignitions are assumed to occur in slash areas. Other human-caused and lightning-caused ignitions are allocated to the area types in proportion to the

*In many of the model runs documented in the following section, the ignitions submodel was not used. The expected number of ignitions in each class, given prevention activities, was assessed and input directly into the fire location submodel. In a more detailed model, ignitions in each class might be expressed as a function of prevention or fuel treatment expenditures.

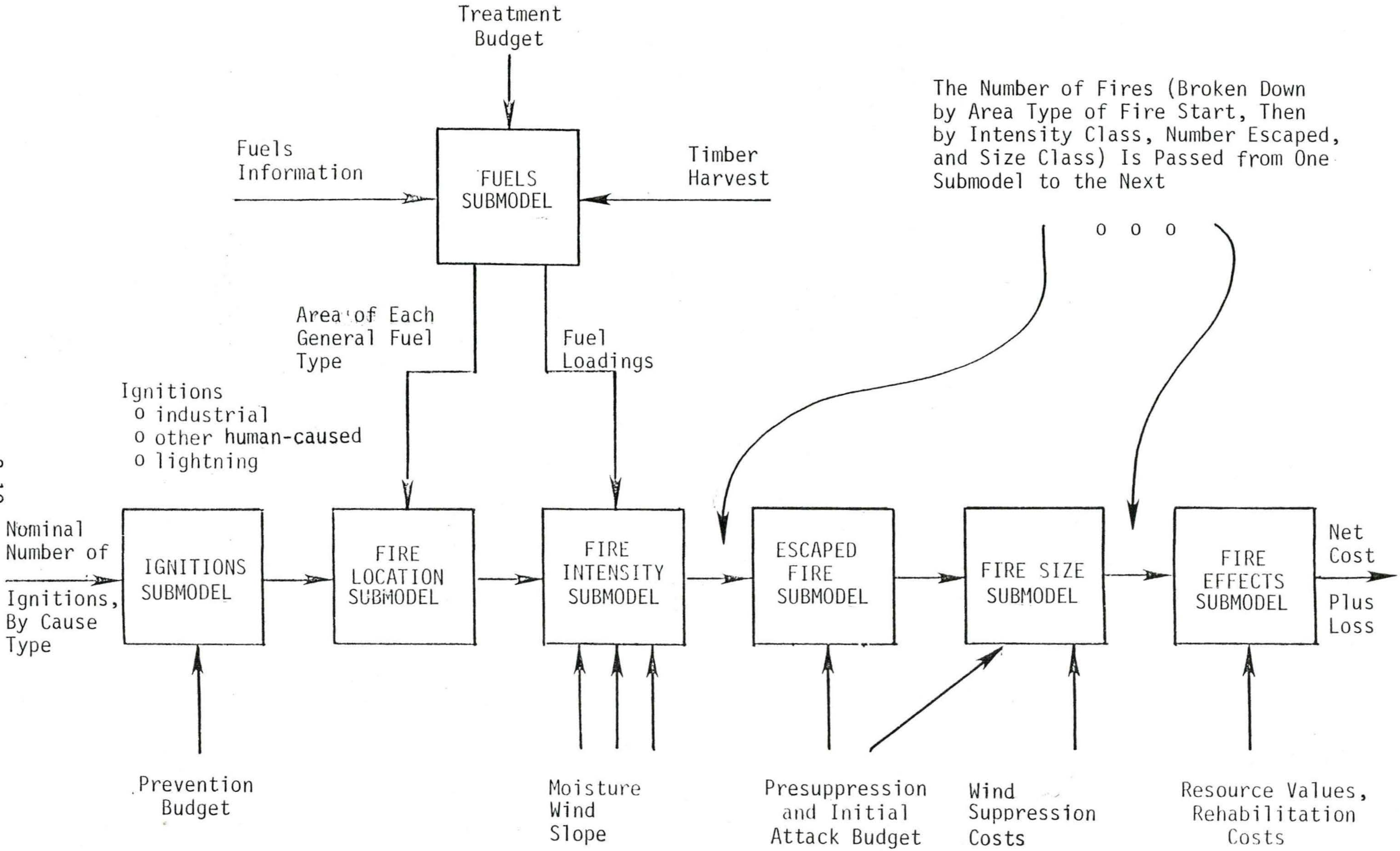


Figure 3-3

COST-PLUS-LOSS MODEL BLOCK DIAGRAM

number of acres assigned to each area type.* Using base case data, the expected number of ignitions per year is about 23 in G areas, 7 in H areas, and 2 each in the I and J areas.

The fire intensity submodel takes as input the number of fires in each area type and assigns the fires to intensity classes. Intensity classes used for most of the analyses were 0 to 100, 100 to 700, and greater than 700 Btu/ft/second. An intensity of 100 Btu/ft/sec is about the limit beyond which people are unable to work at the fire edge. At about 7Btu/ft/sec spotting begins to be a problem and the limit of direct attack is reached. The basis for allocating the fires to intensity classes is a set of discretized approximations to the cumulative probability distributions generated by the FIREBEHAV computer system (incorporating a fire behavior model) previously discussed. A discrete distribution is used for each area type (that is, for each stylized fuel model). For example, for the medium slash (J) stylized fuel model there is a 3% chance of a low-intensity fire (0-100), a 61% probability of a moderate-intensity fire (100-700), and a 36% chance of a high-intensity fire (>700). The complete distributions are listed in Appendix A. On an annual basis, one might expect about 25 fires in the lowest intensity class, about 6 in the intermediate class, and 3 in the highest intensity class.

The escaped fire submodel divides all fires (broken down by area type and intensity class) into those that are controlled by initial attack

*It is possible that a greater proportion of lightning ignitions occur in H areas, since such areas typically are at higher elevations. This would imply a shift of perhaps one or two ignitions from G to H. Such a change would cause the model results to change by only a few percent.

forces and those that escape initial attack. Escaped fires are defined to include those that are controlled by initial attack forces at a size exceeding that of the two lower size classes (nominally, greater than 20 acres) as well as those escaping initial attack. The fraction of fires escaping depends upon the area type (fuel loading) and intensity class and is also affected by expenditures for presuppression activities and fuels treatment. The fractions used were based on the judgement of Mt. Hood fuels and fire management staff and calibrated so that the model results reflect historical experience.

The fire size submodel divides the fires into the size classes noted in the previous section on fire behavior uncertainty. The fraction of fires assumed to be in each size class is a function of area type, intensity class, and whether or not the fires escaped initial attack. The fractions can be interpreted as a discrete probability distribution over fire size, conditional on intensity, stylized fuel model type, and escape status. The distributions used were developed in cooperation with Mt. Hood staff. The final distributions (listed in Appendix A) were developed through an interactive process of subjective judgement and examination of the quantitative implications.

The fire effects submodel assigns costs associated with fires. A table is entered giving the per-acre fire losses such as timber damage and rehabilitation costs in thousands of dollars as a function of area type, intensity class, and size class. A typical cost was $1000 per acre. The full table of costs is included in Appendix A. For each fire category, the per-acre loss is multiplied by the average size of fires in that size

class. Total expected annual losses are then calculated by multiplying these values by the number of fires in each category and totaling overall size classes, intensity classes, and area types. Suppression costs are calculated in a similar manner. Nominal suppression costs were assumed to be $500 per acre (except for the smallest size class). These values are then added to the fire management budget, resulting in the total annual cost plus loss.

The general flow of the cost-plus-loss model is to start out with the expected annual number of ignitions and break them down by location, intensity of the resulting fires, and fire size, as diagrammed in Figure 3-4. Since the effects of fires are generally not linear with size or intensity, the detailed breakdown allows fire damage costs to be assigned in a consistent manner.

The model equations can be summarized as follows:

$$\text{IGNITIONS}(i) = \sum_{\substack{j=\text{industrial}\\ \text{other human-caused}\\ \text{lightning}}} \text{PROPORTION}(j \text{ to } i) \times \text{IGNITIONS}(i)$$

i = area types G, H, I, J

$$\text{TOTAL LOSSES} = \sum_{\substack{\text{area}\\ \text{types}\\ i}} \sum_{\substack{\text{intensity}\\ \text{classes}\\ j}} \sum_{\substack{\text{escape}\\ \text{status}\\ k}} \sum_{\substack{\text{size}\\ \text{classes}\\ l}} \text{IGNITIONS}(i)$$

$$\times \text{INTENSITY}(i,j) \times \text{ESCAPE}(i,j,k) \times \text{SIZE}(i,j,l)$$

$$\times \text{DAMAGE COSTS}(i,j,l)$$

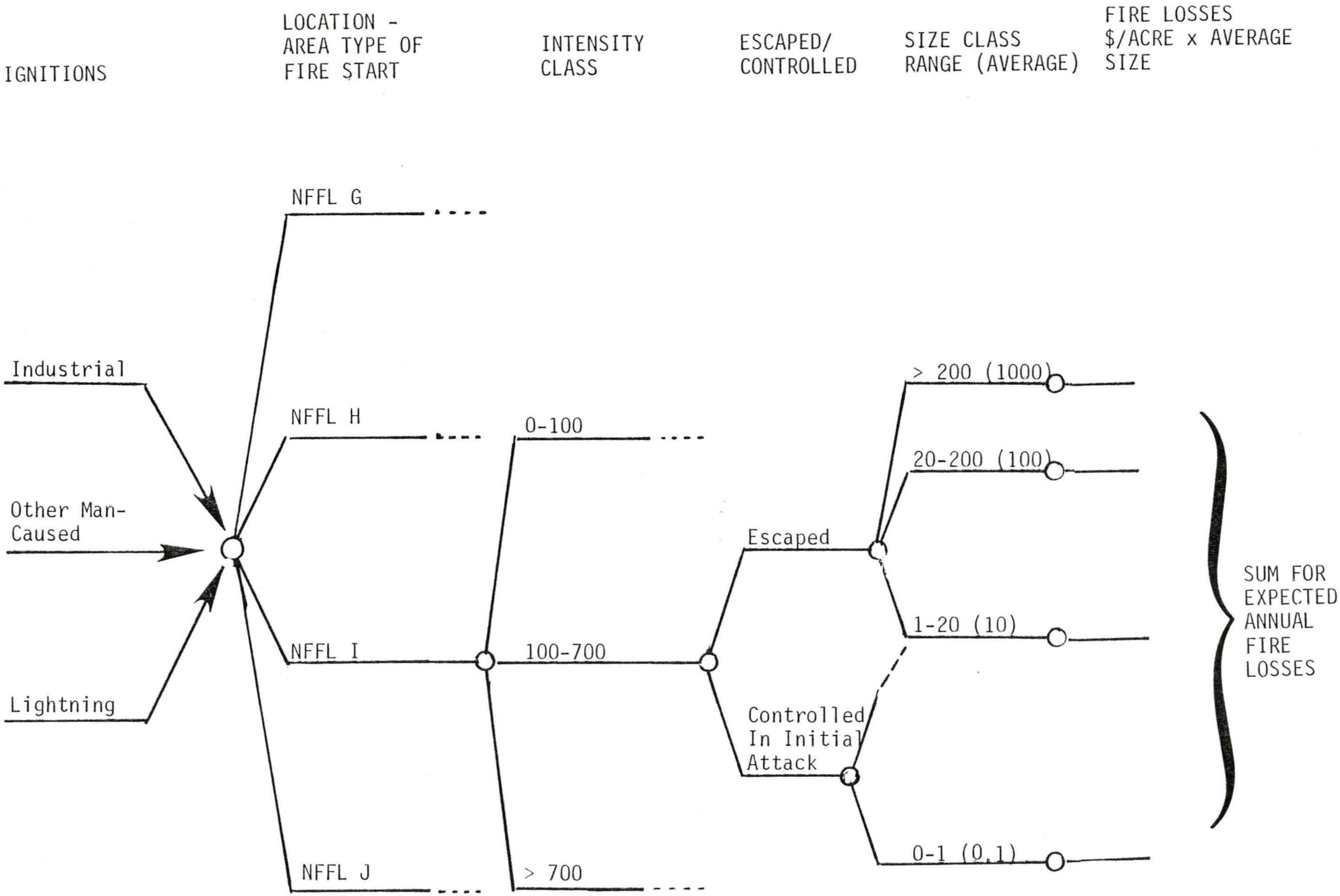


Figure 3-4

FLOW OF COST-PLUS-LOSS MODEL

INTENSITY(i,j) = probability of intensity class j given area type i

ESCAPE(i,j,k) = probability of escape status k (yes or no) given area type i and intensity class j

SIZE(i,k,l) = probability of size class l given area type i and intensity j

DAMAGE COSTS(i,j,l) = damage cost given area type i, intensity class j, and size class l

TOTAL COST + LOSS = TOTAL LOSSES + BUDGET COST

Base Case Data

Data were developed in cooperation with staff from both the Mt. Hood National Forest and the Rocky Mountain Experiment Station. Both historical records and judgement based on on-site experience were used. Data used for the cost-plus-loss model base case are listed in Appendix A.

Base Case Results

Base case results are listed in Tables 3-1(a) and 3-1(b). Table 3-1(a) gives a complete summary, while the detailed results broken down by the type of area in which a fire starts are listed in Table 3-1(b). The number, size distribution, and total burned acres of fires calculated for the base case represent an average of recent experience in the Clackamas and Estacada districts. The numbers are not meant to reflect any particular year. The results do assume a fire management budget at roughly current levels, totaling about $743,000 for the Clackamas and Estacada districts, of which $477,000 is for fuels treatment.

The results show that of the average of 34 annual ignitions, about 28 are controlled as very small fires (see Table 3-1[a], Number of Fires by

Table 3-1(a)

BASE CASE RESULTS: SUMMARY

Area Type of Fire Start (fuel model)	Number of Fires by Size Class (ave/yr) 0.1 Acres	10 Acres	100 Acres	1000 Acres	Total
Heavy Slash (I)	0.54	1.33	0.26	0.03	2.15
Medium Slash (J)	0.97	0.98	0.19	0.02	2.15
Timber Litter (H)	6.27	0.33	0.00	0.00	6.60
Litter+Understory (G)	19.92	2.80	0.35	0.02	23.10
Total	27.70	5.44	0.79	0.07	34.00

Area Type of Fire Start (fuel model)	Number of Fires by Intensity Class (ave/yr) Low (0-100)	Moderate (100-700)	High (>700)	Total
Heavy Slash (I)	0.00	0.60	1.55	2.15
Medium Slash (J)	0.06	1.31	0.77	2.15
Timber Litter (H)	6.60	0.00	0.00	6.60
Litter+Understory G)	18.02	4.39	0.69	23.10
Total	24.68	6.30	3.01	34.00

Area Type of Fire Start (fuel model)	Expected Fire Damages ($1000/yr) (By Area Type and Intensity Class) Low (0-100)	Moderate (100-700)	High (>700)	Total
Heavy Slash (I)	0.00	6.31	64.84	71.15
Medium Slash (J)	0.01	13.55	32.42	45.98
Timber Litter (H)	0.79	0.00	0.00	0.79
Litter+Understory (G)	2.14	74.67	52.13	128.94
Total	2.94	94.52	149.39	246.85

Total Suppression Cost ($1000/yr) = 100.4

Budget (inc. fuels treatment, $1000/yr) = 743

Total Cost Plus Loss ($1000/yr) = 1090

Table 3-1(b)

BASE CASE RESULTS: DETAILS

Area Type: Heavy Slash (I)

Number of Ignitions: 2.15

Number of Fires (ave/yr)
(By Intensity and Size Class)

Intensity Class	0.1 Ave. Acres	10 Ave. Acres	100 Ave. Acres	1000 Ave. Acres	Total
Low (0-100)	0.00	0.00	0.00	0.00	0.00
Moderate (100-700)	0.36	0.21	0.03	0.00	0.60
High (>700)	0.19	1.11	0.22	0.03	1.55
Total	0.54	1.33	0.25	0.03	2.15

Fire Damage ($1000/yr)
(By Intensity and Size Class)

Intensity Class	0.1 Ave. Acres	10 Ave. Acres	100 Ave. Acres	1000 Ave. Acres	Total
Low (0-100)	0.00	0.00	0.00	0.00	0.00
Moderate (100-700)	0.02	1.05	3.43	1.81	6.31
High (>700)	0.01	8.36	26.75	29.72	64.84
Total	0.03	9.41	30.18	31.53	71.15

Table 3-1(b) continued

BASE CASE RESULTS: DETAILS

Area Type: Medium Slash (J)

Number of Ignitions: 2.15

Number of Fires (ave/yr)
(By Intensity and Size Class)

Intensity Class	0.1 Ave. Acres	10 Ave. Acres	100 Ave. Acres	1000 Ave. Acres	Total
Low (0-100)	0.06	0.00	0.00	0.00	0.06
Moderate (100-700)	0.81	0.42	0.07	0.00	1.30
High (>700)	0.09	0.56	0.12	0.02	0.79
Total	0.96	0.98	0.19	0.02	2.15

Fire Damage ($1000/yr)
(By Intensity and Size Class)

Intensity Class	0.1 Ave. Acres	10 Ave. Acres	100 Ave. Acres	1000 Ave. Acres	Total
Low (0-100)	0.00	0.00	0.00	0.00	0.01
Moderate (100-700)	0.04	2.10	7.48	3.93	13.55
High (>700)	0.00	4.18	13.37	14.86	32.42
Total	0.05	6.28	20.85	18.80	45.98

Table 3-1(b) continued

BASE CASE RESULTS: DETAILS

Area Type: Tember Litter (H)

Number of Ignitions: 6.6

Number of Fires (ave/yr)
(By Intensity and Size Class)

Intensity Class	0.1 Ave. Acres	10 Ave. Acres	100 Ave. Acres	1000 Ave. Acres	Total
Low (0-100)	6.27	0.33	0.00	0.00	6.60
Moderate (100-700)	0.00	0.00	0.00	0.00	0.00
High (>700)	0.00	0.00	0.00	0.00	0.00
Total	6.27	0.33	0.00	0.00	6.60

Fire Damage ($1000/yr)
(By Intensity and Size Class)

Intensity Class	0.1 Ave. Acres	10 Ave. Acres	100 Ave. Acres	1000 Ave. Acres	Total
Low (0-100)	0.13	0.66	0.00	0.00	0.79
Moderate (100-700)	0.00	0.00	0.00	0.00	0.00
High (>700)	0.00	0.00	0.00	0.00	0.00
Total	0.13	0.66	0.00	0.00	0.79

Table 3-1(b) continued

BASE CASE RESULTS: DETAILS

Area Type: Timber Litter plus Understory (G)

Number of Ignitions: 23.1

Number of Fires (ave/yr)
(By Intensity and Size Class)

Intensity Class		0.1 Ave. Acres	10 Ave. Acres	100 Ave. Acres	1000 Ave. Acres	Total
Low	(0-100)	17.12	0.90	0.00	0.00	18.02
Moderate	(100-700)	2.72	1.40	0.25	0.01	4.39
High	(>700)	0.08	0.50	0.10	0.01	0.69
Total		19.92	2.80	0.35	0.02	23.10

Fire Damage ($1000/yr)
(By Intensity and Size Class)

Intensity Class		0.1 Ave. Acres	10 Ave. Acres	100 Ave. Acres	1000 Ave. Acres	Total
Low	(0-100)	0.34	1.80	0.00	0.00	2.14
Moderate	(100-700)	0.27	21.07	37.53	15.80	74.67
High	(>700)	0.01	9.98	19.96	22.18	52.13
Total		0.63	32.85	57.48	37.98	128.94

Size Class). Fires reaching an average size of 10 acres occur at an average rate of roughly five per year. One might expect a fire in the 100-acre class once every one to two years and a very large fire (of approximately 1000 acres) about once every 15 years. Note that these are to be interpreted as long-run averages. The occurrence of a large fire in any given year does not imply that several years must pass before another is possible.

Examination of the base case summary results leads to some interesting observations. Fires in the highest intensity class lead to over 60% of fire damage costs, while the expected number of such fires is about three per year (see Table 3-1[a], Expected Fire Damages and Number of Fires by Intensity Class). It is reasonable that the most intense fires have the greatest chance of burning over a large area and causing the greatest damage to timber and other resources. Although only about 13% of the fires start in areas best represented by slash stylized fuel models, such fires account for over 47% of all fire damage costs (see Table 3-1[a]). It follows directly that fires starting in slash have a greater chance of reaching higher intensities than do those starting in timbered areas. The H type of stylized fuel model is almost fireproof under the weather conditions of the Mt. Hood National Forest. All fires in areas represented by this model were in the lowest intensity class, resulting in almost insignificant damages.

SENSITIVITY ANALYSIS

Sensitivity analysis serves two purposes. Its primary intent is to identify which of the many uncertain parameters are critical to a given

decision. This identification allows the uncertainty in the variables to which the decision is most sensitive to be represented explicitly by a probability distribution. Such a representation is prerequisite to any calculations of the economic value of improved information. The second purpose of sensitivity analysis is to provide insight into the behavior of the system. This was particularly useful in the analysis of the fire management budget level decision.

Because of the uncertainty in the effectiveness of fire management budget expenditures--in particular, uncertainty in the effects of changes in budget--we chose not to attempt to optimize the budget level. Rather, we analyzed several parameters of the budget decision, exploring a range of assumptions about budget effectiveness. Because of the parametric approach, we did not use the standard practice of directly testing the sensitivity of the decision to uncertainty in important variables. Instead, the method used involved carrying out extensive tests of the sensitivity of the outcomes (primarily fire losses) to variations in input values and assumptions. The sensitivity information was then used as a basis for understanding, in a qualitative sense, the sensitivity of the budget decision to the inputs and assumptions.

A representative set of sensitivity tests is listed in Table 3-2. Data used in the sensitivity tests are listed at the end of Appendix A.

Critical Uncertainties

The sensitivity analysis showed that the fire loss estimates are most sensitive to variations in the distribution of area (or fuel) types and to changes in fire intensity given the fuel type. As listed in Table 3-2,

Table 3-2

SENSITIVITY ANALYSIS
(Thousands of Dollars Per Year)

Sensitivity Case	Expected Fire Losses	Expected Suppression Costs	Losses + Suppression Costs: Difference From Base Case
Base Case	247	100	---
Ignitions			
Subtract One Industrial Ignition	220	88	-39
Subtract One Other Human-Caused Ignition	240	98	-9
Slash Area			
50% Less Slash Area	202	80	-65
100% More Slash Area	369	164	+186
Fire Intensitiy			
2 x Fire Intensities	560	191	+404
1/2 x Fire Intensities	200	84	-63
Number of Escaped Fires			
10% More Escaped Fires	268	109	+30
25% More Escaped Fires	301	121	+75
10% Fewer Escaped Fires	225	92	-30
25% Fewer Escaped Fires	193	80	-74
Values			
2 x Fire Damage Cost Values	494	100	+247
1/2 x Fire Damage Cost Values	123	100	-124

increasing the assessed area represented by slash stylized fuel models by 100% results in a 50% increase in the expected losses. This change occurs even though only 10% of the total area has been changed from the G or H to the I or J fuel types. Similarly, doubling the fire intensities more than doubles fire losses. A greater percentage of areas with high fuel loadings will lead to more fires having higher intensities. As was noted in the discussion of the base case results, these are the fires that have the greatest losses. An analogous effect is clear if all fires have higher intensities.

The great sensitivity of the outcomes to changes in the distribution of area types and fire intensities suggests that the budget decision will also be sensitive to such uncertainties. For example, if one assumes that greater budget expenditure results in improved control effectiveness, such an increased budget is preferable given a greater percentage of area with high fuel loadings. On the other hand, lower fire intensities, less area with high fuel loadings, or a combination of the two implies that the budget may be reduced with a net reduction in cost plus loss. (The fire intensity and area distribution uncertainties are modeled explicitly in the subsection Value of Information Analysis. The economic value of obtaining more information to reduce the uncertainties is discussed at that point.)

The outcomes of the annual budget decision are also sensitive to the annual number of ignitions. The optimal alternative varies symmetrically with the number of ignitions: more ignitions suggest a higher budget, and vice versa. This sensitivity was not so great as that found for area distribution and intensity. Furthermore, few information-gathering options

are available to reduce uncertainty in the number of future ignitions.* Thus it was appropriate to evaluate the budget decision and value of information analyses on the basis of the expected annual number of ignitions.

Initially weather uncertainty seemed to be critical. Enough historical information is available that the annual weather pattern is known within a relatively narrow range. Predicting the weather for a single day is difficult, but the fire budget decision depends on annual characteristics, not on day-to-day variations. It seems reasonable to conclude that the decision is relatively insensitive to the low degree of uncertainty in the annual weather pattern. Spacial weather variations are important for detailed preattack planning but do not significantly affect the overall annual budget decision.

The effectiveness of various fire management and fuels treatment expenditures--that is, the effectiveness of the fire budget--is of considerable importance. It is also poorly understood. In formal terms, there is a wide range of uncertainty in control effectiveness given budget level. In the present analysis, this uncertainty was investigated in two ways: the value of information on other parameters was calculated for a range of assumptions regarding budget effectiveness, and a simplified value of information calculation was carried out for the uncertainty in effectiveness itself.

*This does not imply that expenditures on prevention activities will not reduce the number of ignitions; that is an action that changes the system rather than information gathering.

The losses that should be associated with fires are values that are subject to much debate. While timber values are reasonably well known, the reduction in such values caused by fires (of varying intensity and extent) is uncertain. Other resource values, such as watershed or wildlife, are rarely found to have explicit quantitative value assignments. Rather than interpreting this as an uncertainty that might be reduced with further information, we chose to evaluate the decision and the value of information for other parameters for a range of fire damage costs or losses. The sensitivity of such values to variations in the losses is then evident.

We have not included an explicit test of sensitivity to the size distributions (e.g., to the distribution of fire sizes given area type, intensity, and escape status). The outcomes will clearly be sensitive to the probabilities of large fires. The distributions used (as listed in Appendix A) reflect the best judgement of several Mt. Hood fuels and fire managers and are also consistent with historical data. We have chosen to hold these distributions fixed, as a modeling assumption, to reduce the degrees of freedom in the model.

Insights from Sensitivity Analysis

The importance of sensitivity analysis goes beyond its role in identifying critical uncertainties. It can provide insights to help in understanding the system and decisions. An example of such insight is the importance of uncertainty in annual as opposed to daily weather. The outcomes depend on the annual weather pattern, yet it is the daily weather variations that are highly uncertain.

Because of the uncertainty in budget effectiveness, it is not possible to provide a detailed analysis of the allocation of the overall fire management budget to particular budget categories. The sensitivity analyses do give, however, some feel for this issue. For example, the annual expected values of eliminating one industrial ignition or one other-human-caused ignition are, respectively, about $39,000 and $9,000. The costs of having an additional ignition in either category are similar. These values compare to a current prevention budget of about $58,000 for the Clackamas and Estacada districts. If the prevention budget effectiveness is such that the number of nonindustrial ignitions can be expected to be reduced by one for an additional expenditure of less than $9,000, such a budget allocation is worth considering. On the other hand, if reducing the prevention budget by an amount greater than $9,000 led to an increase in the expected number of ignitions by less than one, then such an alternative should be evaluated.

The effectiveness of fuels treatment activities is subject to some controversy. While the scope of analysis precludes detailed investigation of this issue, the sensitivity analysis may provide some insight. If the amount of area having a fuel load best represented by the slash stylized fuel models could be reduced by 50%, the action would have a value in the first year on the order of $65,000.* This expected saving would accrue over each year that the slash area was maintained at a level of 50% below the present level. Comparing the costs of such treatment activities with

*Recall that this is for the Clackamas and Estacada districts only. The value would be greater for the entire Mt. Hood National Forest.

this value will give some feel as to whether the present fuels treatment budget of $477,000 is appropriate.

Holding all other factors constant (in particular, area distribution and fire intensities), the value of reducing the number of escaped fires by 10% is about $30,000 per year. Conversely, the cost of allowing 10% more fires to escape initial attack is similar. If increasing the presuppresion budget by an amount less than $30,000 can achieve a 10% reduction in escapes, such a budget increase would be desirable. If more than $30,000 can be saved from the budget by allowing 10% more fires to escape, this alternative should be seriously considered.

VALUE OF INFORMATION ANALYSIS

Three different values of information analyses were carried out for the fire management budget decision. The value of reducing uncertainty in the assignment of forest area to the available stylized fuel model types and in fire intensity given fuel type was investigated in some detail. Briefer discussions of the value of information on budget effectiveness and the value of adding an additional stylized fuel model to the available set follow.

Value of Information: Fuels and Fire Intensity

Before examining the value of information in detail, it is necessary to define completely the specific decision being analyzed. In general terms, the alternatives are to raise the fire management budget, maintain it at the present level, or lower the budget. Several different amounts of potential budget increase or decrease were investigated. The uncertainties

considered explicitly are the assignment of stylized fuel models to the total area (area distribution) and the fire intensity given fuel type and weather characteristics (intensity). The outcomes are total budget, fire damage costs, and suppression costs. The decision criterion is to minimize net costs plus losses. Other than for budget alternatives, area distribution, and intensity, all data used reflect the base case discussed earlier in this section. (Data for the base case are summarized in Appendix A.)

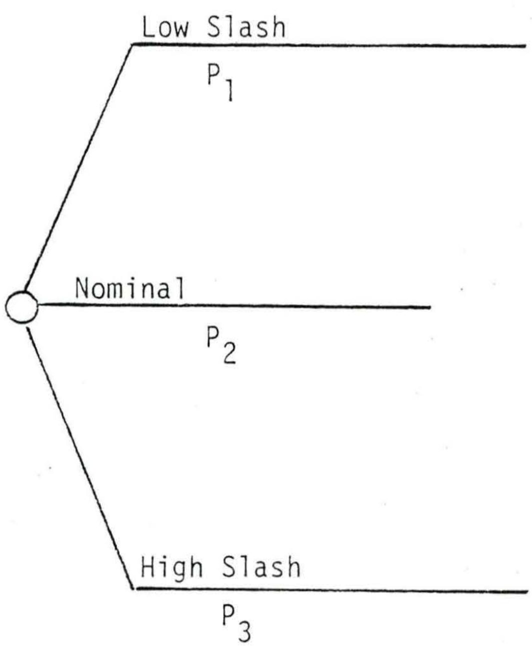
A difficult question, given the complexity and uncertainty, was how to model the change in fire control effectiveness, given changes in budget. A parametric approach was used, providing an internally consistent framework for evaluation. It was assumed that changes in fire management budget change the probability of controlling a fire with initial attack forces. This could occur through changes in presuppression, fuels treatment, or initial attack activities. Changing the probability of achieving control during initial attack implies a change in the number of escaped fires--the dominant category in fire losses. Two cases were examined, one in which increasing or decreasing the fire budget causes a 10% increase or decrease in the number of escaped fires and one in which a budget increase or decrease results in a 50% increase or decrease in escapes. The magnitude of budget change needed for these effectiveness changes was varied, providing a range for the value of information calculations.

Note that we are examining decisions involving incremental changes in the budget level. Similar incremental decisions at different base budget levels are likely to result in information values of the same order of magnitude as those found in this case study.

Area Distribution Uncertainty. The uncertainty in the assignment of stylized fuel models to the Clackamas and Estacada districts is represented in Figure 3-5. The range of possible assignments was approximated by a discrete probability distribution over the three breakdowns: a nominal (or most likely) distribution, a low-slash case, and a high-slash case. The probability distribution was based on assessments of Mt. Hood staff, as encoded by DFI personnel.* The encoding session involved five fuels and fire managers; the state of information shown in Figure 3-5 represents their consensus view. The reduced uncertainty case can be given two alternative interpretations: (1) for a national forest such as the Mt. Hood, the uncertainty remaining after more (but still imperfect) information is available, or (2) the initial uncertainty for a forest having more information on fuel loadings at the outset.

Fire Intensity Uncertainty. The uncertainty in intensity, given fuel type, is represented in Figure 3-6. As noted previously, intensities used are those calculated by a fire behavior model. Discussions with model developers and users suggested that actual fireline intensities can be expected to fall in the range of one-half of the nominal model-generated intensity up to twice the nominal intensity output. This uncertainty in fireline intensity is approximated by the nominal probability distribution listed in Figure 3-6 at the half nominal, nominal, and two-times-nominal intensities.

*The probabilities used (0.25, 0.5, 0.25) reflect a discrete approximation to the continuous distribution implied by the consensus that the probability of the amount of slash exceeding the high-slash case or falling below the low-slash case is low.

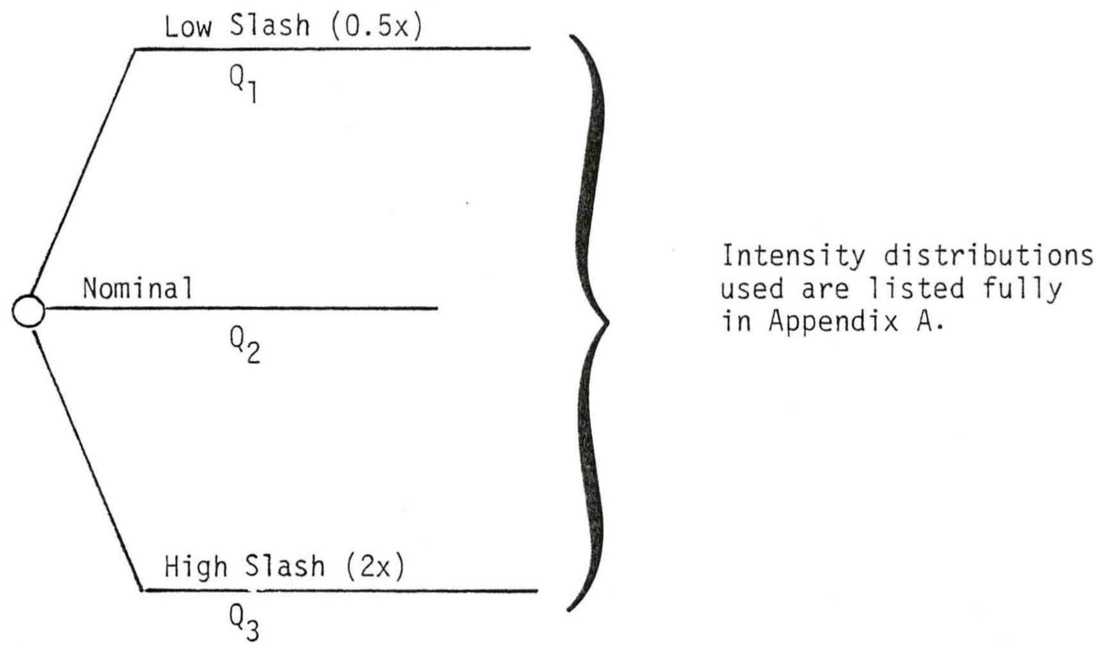


	Acres Assigned to Each Stylized Fuel Model (x1000)			
	I	J	H	G
Low Slash (P_1)	10	10	100	280
Nominal (P_2)	20	20	80	280
High Slash (P_3)	40	80	80	200

Probability Distributions	P_1	P_2	P_3
Nominal Uncertainty	0.25	0.5	0.25
Reduced Uncertainty	0.1	0.8	0.1

Figure 3-5

AREA DISTRIBUTION UNCERTAINTY



Probability Distributions	Q_1	Q_2	Q_3
Nominal Uncertainty	0.25	0.5	0.25
Reduced Uncertainty	0.1	0.8	0.1

Figure 3-6

FIRE INTENSITY UNCERTAINTY

Each of the three cases forming the branches of the probability node in Figure 3-6 is actually a set of four distributions (with weather variations factored in) on fireline intensity, one for each fuel model type. The discretized versions of these data are shown in Appendix A: the nominal case is covered with the base case data, and the 0.5 and 2 times cases are under the sensitivity data.

Decision Tree. The complete decision tree used for the analysis of the value of information on area distribution and fire intensity is shown in Figure 3-7. Outcome values (total cost plus loss) are listed for two decision situations, for which the alternatives of raising or lowering the fire budget result in either a 10% change or a 50% change in the number of fires escaping control in initial attack. The budget increments necessary to produce these changes in effectiveness--that is, the budget changes implied by the increase or decrease alternatives--are denoted as Δ_1 and Δ_2. The uncertainties in the distribution of fuel model types and in fire intensities are shown explicitly. Probabilities for the area distribution uncertainty are shown in Figure 3-5. Probabilities describing the uncertainty in intensity are listed in Figure 3-6.

Analysis. A range of cases was evaluated. The optimal alternative and expected value given the initial uncertainty, the value of perfect information on the area distribuiton, and the value of perfect information of fire intensity were determined for each case. Varied over the cases are the effect of the budget increase or decrease alternatives (+/- 10% or +/- 50%), the cost of effecting these changes (Δ_1 and Δ_2), and the

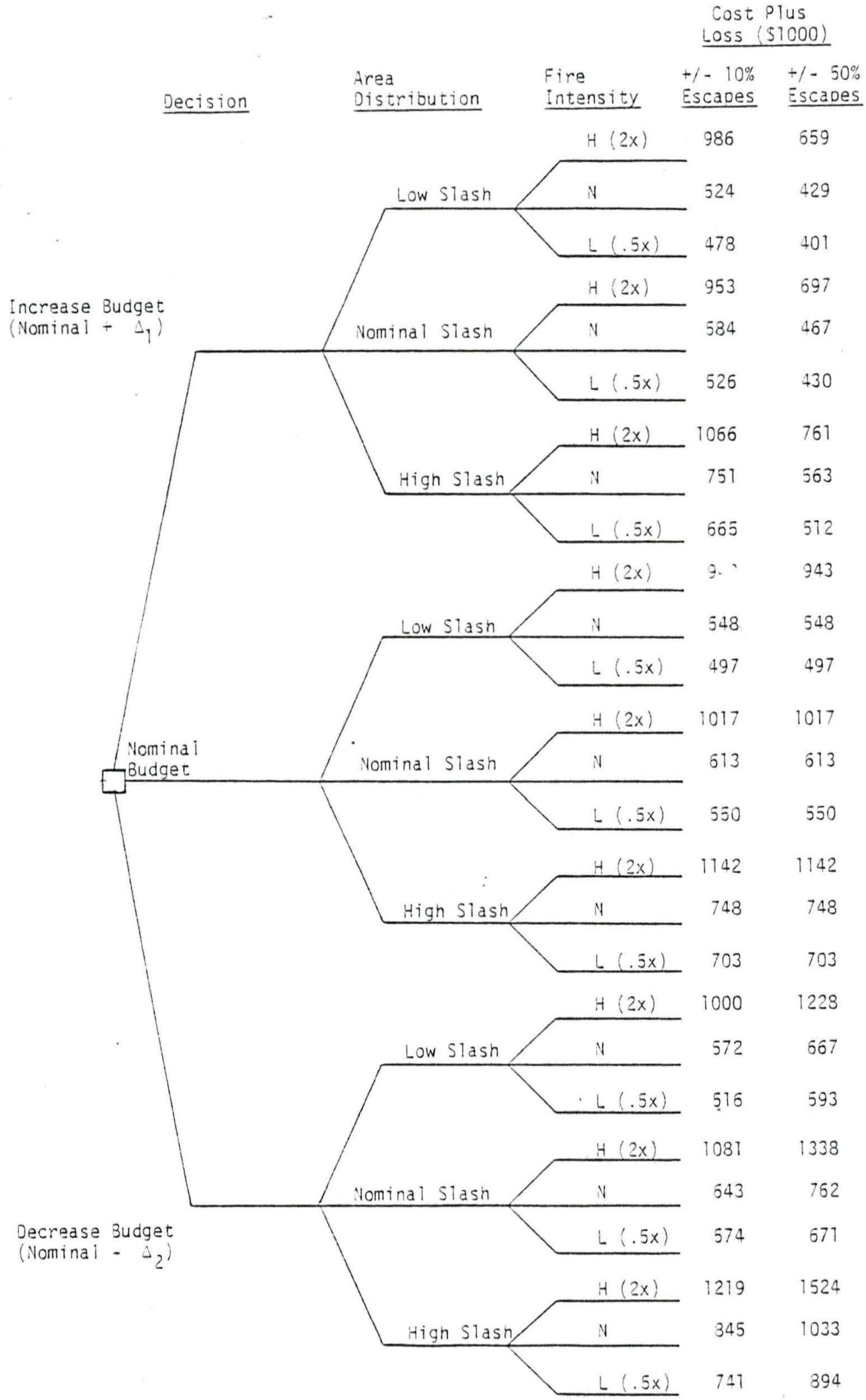


Figure 3-7

BUDGET ANALYSIS DECISION TREE

initial uncertainty in area distribution and intensity (see figures 3-5 and 3-6). Summaries of some of the most interesting cases are provided in Table 3-3. These are cases for which the settings of Δ_1 and Δ_2 result in some positive value of information. Many more cases could be defined for which the settings of Δ_1 and Δ_2 result in one alternative's being dominant, implying no value of information. Thus, the cases shown give an idea as to the magnitude of an upper bound on the expected value of perfect information in the context of the budget decision. A full list of cases can be found in Tables 3-4(a) and 3-4(b). Information values are given in dollars per acre per year.

For decisions involving relatively small changes in the budget level (on the order of 10-20%), the value of obtaining perfect information on the distribution of area types was very small, typically less than one cent per acre per year. Most annual decisions regarding budget level will involve alternatives of this magnitude, which corresponds to an information value of roughly $10,000 per year for the Mt. Hood National Forest. Recall that this is the value of perfect information; most information-gathering alternatives will still leave one short of certainty. Again, for decisions involving incremental changes in budget, the value of perfect information on fire intensity was generally in the range of one to three cents per acre per year, which corresponds to $10,000 to $30,000 per year for the Mt. Hood National Forest. Representative cases are found in Table 3-3, scenarios 1 through 5.

When decisions involving greater changes in resource allocations are considered, it is reasonable to expect that the value of reducing

Table 3-3

VALUE OF INFORMATION CASES: SUMMARY

Decision Scenario	Best Alternative Under Uncertainty	Expected Cost + Loss ($1000/yr)	Expected Value of Perfect Information ($/acre/yr)	
			On Area Distribution	On Fire Intensity
1. Alternatives Include Nominal and +/-10% of Presuppression, Prevention and Initial Attack Budget to Produce +/-10% in Escapes	Increase Budget	729	$0.00	$0.009
2. Same as 1, except with Low Initial Uncertainty on Intensity	Nominal Budget	668	$0.006	$0.01
3. Alternatives Include +/-15% of Budget to Produce +/-10% Escapes	Nominal Budget	773	$0.007	$0.03
4. Same as 3, except 3 with Low Initial Uncertainty on Both Area and Intensity	Decrease Budget	652	$0.01	$0.01
5. Alternatives Include +/10%/-20% of Budget to Produce +/-10% Escapes	Increase Budget	729	$0.01	$0.03
6. Alternatives Include +/-60% of Budget to Produce +/-50% in Escapes	Increase Budget	698	$0.00	$0.05
7. Alternatives Include +75%/-50% of Budget to Produce +/-50% Escapes	Nominal Budget	737	$0.03	$0.10

Table 3-4 (a)

VALUE OF INFORMATION RESULTS FOR SCENARIOS INVOLVING +/-10% OF ESCAPED FIRES

Δ_1 (% of Budget)	Δ_2 (% of Budget)	Area Distribution Uncertainty*	Fire Intensity Uncertainty*	Best Alternative Under Uncertainty*	Expected Value ($1000)	EVPI (Annual $/acre) On Fuel Load and Location	EVPI (Annual $/acre) On Fire Intensity
10	10	N	N	+	729	$0.00	$0.009
10	10	N	R	N	668	0.006	0.01
10	10	R	N	+	712	0.00	0.004
10	10	R	R	+	652	0.004	0.003
15	15	N	N	N	737	0.007	0.03
15	15	R	R	-	652	0.01	0.01
10	15	N	N	+	729	0.001	0.02
15	10	N	N	N	737	0.00	0.02
10	20	N	N	+	729	0.01	0.03
20	10	N	N	N	737	0.00	0.009
5	10	N	N	+	716	0.00	0.00
10	5	N	N	+	729	0.00	0.009

* N = Nominal
R = Reduced
\+ = Increase
\- = Decrease

Table 3-4 (b)

VALUE OF INFORMATION RESULTS FOR SCENARIOS INVOLVING +/-50% OF ESCAPED FIRES

Δ_1 (% of Budget)	Δ_2 (% of Budget)	Area Distribution Uncertainty*	Fire Intensity Uncertainty*	Best Alternativs Under Uncertainty*	Expected Value ($1000)	EVPI (Annual $/acre) On Fuel Load and Location	EVPI (Annual $/acre) On Fire Intensity
50	50	N	N	+	672	$0.00	$0.00
60	60	N	N	+	698	0.00	0.05
40	40	N	N	+	645	0.00	0.00
75	75	N	N	N	737	0.07	0.16
75	75	N	R	-	640	0.02	0.01
75	75	R	N	-	722	0.03	0.19
75	75	R	R	-	627	0.02	0.06
60	30	N	N	+	698	0.00	0.03
30	60	N	N	+	618	0.00	0.00
75	50	N	N	N	737	0.03	0.10
75	50	N	R	N	668	0.004	0.03
50	75	N	N	+	672	0.007	0.05
50	25	N	N	+	672	0.00	0.00
25	50	N	N	+	605	0.00	0.00

* N = Nominal
R = Reduced
\+ = Increase
\- = Decrease

uncertainty will be greater. The analysis results confirm this supposition. When a major decision is contemplated, such as raising or lowering the budget by about 50% of the present level, the value of reducing uncertainty increased significantly. The expected value of perfect information (EVPI) on the distribution of area types, in the context of such major decisions, ranged from zero to three cents per acre per year. The value of information on fire intensity was as high as nineteen cents per acre. The typical range was five to ten cents per acre per year (see scenarios 6 and 7 in Table 3-3). For the Mt. Hood, one cent per acre corresponds roughly to $10,000.

Some general patterns are apparent in the range of situations analyzed. The value of reducing uncertainty in fire intensity, given fuel model type, was virtually always greater than that for uncertainty in the area distribution of fuel models. Many situations in which more information on the distribution of fuels would not change the budget decision--and thus would have no economic value--still showed a positive EVPI for fire intensity.

For either uncertain parameter, changing the initial probability from the nominal to the reduced uncertainty case resulted in a reduction in the EVPI of 50-75%. One might conclude that the value of new information that would allow this degree of reduction in uncertainty is about one-half of the nominal EVPI. This implies that the value of such imperfect information on the distribution of fuel types for the Mt. Hood National Forest is no more than $5000 per year in the context of annual incremental budget decisions. The value of improved but imperfect information on fire

intensity would be about $10,000 annually. These values would be about three times larger if decisions regarding major portions of the budget (e.g., 50%) were faced.

An interesting pattern found for decisions involving relatively small fractions of the existing budget was that reducing the initial uncertainty in fire intensity often induced an increase in the EVPI on the area distribution. This suggests that a synergism may exist: investing resources in developing an improved fire behavior model (and thus reducing uncertainty in intensity given fuel distribution) can actually increase the value of gathering more information on fuel load and distribution.

Situations in which the effectiveness/budget relationship was assumed to be linear about the nominal budget level (equivalently, constant return to scale) generally had lower information values than were found for cases in which the budget increase required for improved effectiveness was significantly different from that saved in return for accepting less effectiveness. For example, scenario 1 in Table 3-3 is a case in which a 10% increase or decrease in budget results in the same (+/- 10%) change in effectiveness (the number of escaped fires). This decision scenario has very low EVPI values: zero for information on fuels distribution and $0.009/acre/year on fire intensity. In constrast, in scenario 5, the budget could be cut by 20% at the cost of accepting 10% more escapes, while decreasing the number of escapes by 10% requires only half the budget change (e.g., a 10% increase). This case has considerably greater EVPI results: $0.01/acre/year for fuels information and $0.03/acre/year for fire intensity information. This general pattern is reasonable: the

nonlinear scenarios imply greater sensitivity to surprises or unlikely outcomes. Thus, the value of eliminating uncertainty in such cases is likely to be greater.

Value of Adding a Fuel Model

Part of the uncertainty in the assignment of the Clackamas and Estacada area to stylized fuel model types can be attributed to the small number of such types from which one must choose. It is reasonable to wonder whether a finer grained set of fuel models would eliminate or reduce uncertainty. To this purpose, we investigated the value of adding an additional stylized fuel model whose fire behavior characteristics fell between the NFFL I and J models.

A decision problem was set up in which it was assumed as an extreme case that all uncertainty in the area distribution was due to an insufficiently detailed set of stylized fuel models and that all such uncertainty could be removed by the addition of one more model. This structure should provide an upper bound on the value of adding an additional fuel model to the existing set in the context of fire management budget decisions.

The upper decision tree in Figure 3-8 describes the decision situation when only the existing set of fuel models is available. The uncertainty as to how the area should be assigned to the available stylized models is shown explicity. The lower tree in the figure represents the situation when another stylized model is available; no uncertainty remains (again, note that this is purposely an extreme case). The decision alternatives

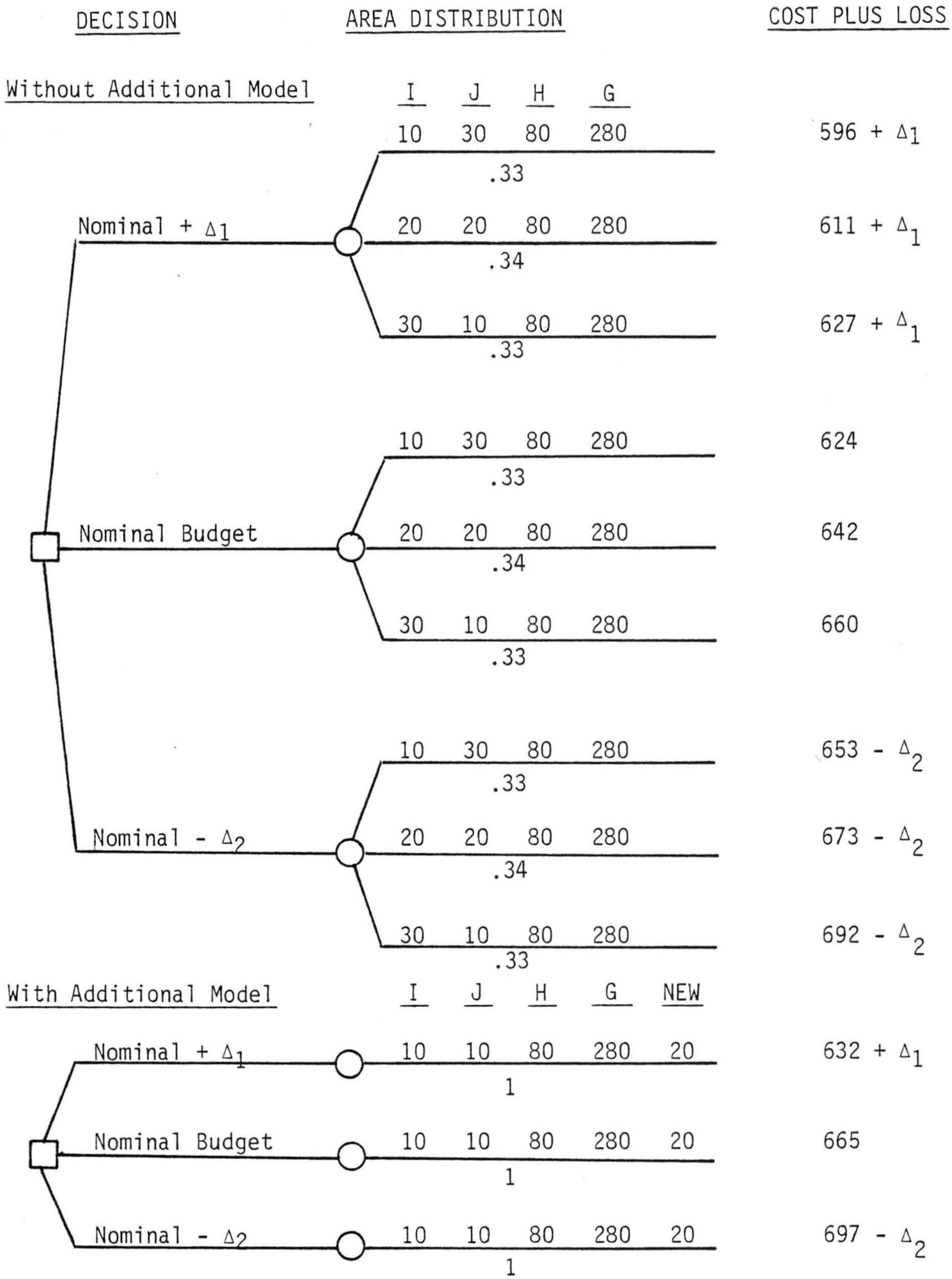


Figure 3-8

DECISION TREES WITHOUT AND WITH AN ADDITIONAL STYLIZED FUEL MODEL

are again whether to increase the fire management budget, leave it at the current level, or decrease the budget. The effectiveness of increasing or decreasing the budget was modeled by a 10% increase or decrease in the number of escaped fires. The uncertainty in budget effectiveness was explored by varying Δ_1 and Δ_2 over a wide range to ascertain the sensitivity to these parameters.

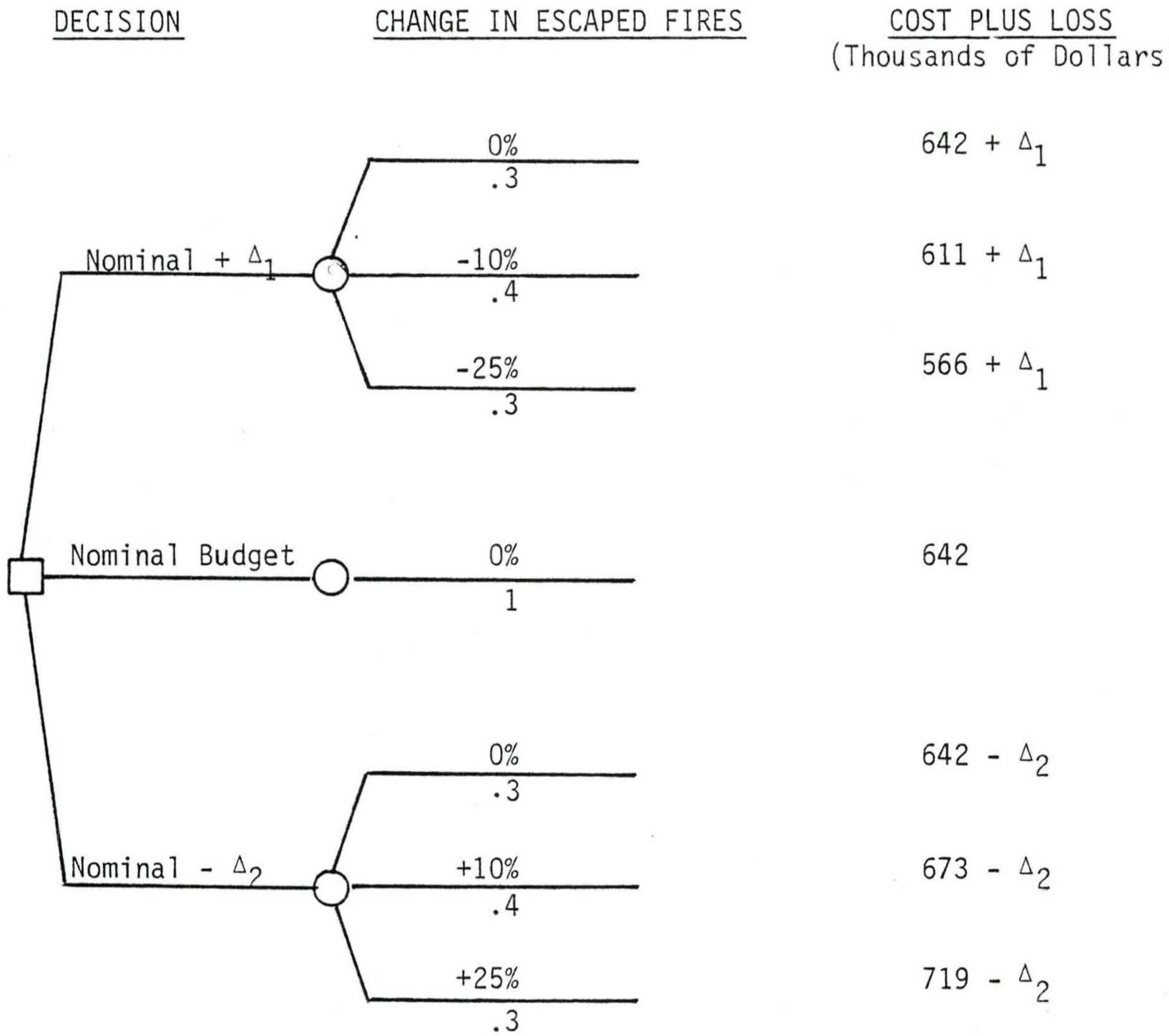
The results of this analysis were rather clear: adding an additional fuel model (and thus removing a source of uncertainty) generally did not result in a change in the preferred alternative. In such cases, since the additional model failed to change the decision, its availability had no value. A few instances (settings of Δ_1 and Δ_2) were found in which a different alternative was shown to be optimal after a fifth fuel model was used. Such cases, however, were those in which the alternatives resulted in outcomes that were so close that the cost of a "wrong" decision was insignificant. For example, in a case where both Δ_1 and Δ_2 were assumed to be $32,000 (about 12% of the nominal budget), the decision problem with uncertainty in area assignment to the four stylized models had as its optimal choice the nominal budget alternative. The budget increase alternative is preferred if the additional fuel model is used to eliminate uncertainty. When the alternative from the first four-model case (nominal budget) is examined in the five-model decision structure, it implies an increase in cost plus loss of only $1000, or approximately one tenth of one percent. These results are insensitive to variations of 50-200% in the area allocated to the hypothetical new stylized fuel model.

We would conclude that for the purposes of budget-level decision in areas such as the Mt. Hood National Forest, the existing set of NFFL fuel models provides significant resolution. A more detailed set of models may be of value for other decision contexts.

Value of Information: Budget Effectiveness

It has been noted several times that the fire management budget effectiveness is uncertain. It is not well understood how great a change in effectiveness (and, ultimately, fire losses) will result from a given change in the budget. In the analyses presented earlier, the implications of this uncertainty were examined by calculating information values for a range of effectiveness change/budget change scenarios. At this point, we will examine the uncertainty explicitly with a simplified decision problem.

The decision tree for this analysis is shown in Figure 3-9. Uncertainty in area distribution and fire intensity is suppressed. It was assumed that it was uncertain what change in the number of escaped fires would result from a given change in budget. The three points modeled in the tree are no change, 10% change, and 25% change. Again, a range of budget change levels was examined to produce a range for the expected value of perfect information. Typical values were about five cents per acre per year (see Figure 3-9), or about $50,000 annually for the Mt. Hood National Forest. It should be reiterated that this is the value of perfect information and thus an upper bound on the cost of any information-gathering efforts. It is unlikely that much of the uncertainty can be eliminated from the budget/effectiveness relationship.



Budget Change (% of Nominal)		EVPI
Δ_1	Δ_2	($/Acre/Yr)
10%	10%	$0.05
15%	15%	0.05
20%	20%	0.04
10%	15%	0.06

Figure 3-9

DECISION TREE FOR EVALUATING EVPI ON
BUDGET EFFECTIVENESS

INFORMATION ALTERNATIVES

Fuel Loading/Distribution of Fuel Types

The EVPI on the distribution of area types was on the order of $10,000 per year for the Mt. Hood. This is clearly not enough to support any significant ground-level information-gathering activity. Some expenditure up to this level on efforts intended to improve the classification of the forest by fuel model type may be merited and could include such alternatives as periodic examination by air of slash/brush conditions in old cut-blocks or use of an improved system of records-keeping to better utilize information already available (e.g., from timber cruises, timber sale records, fuels treatment activities, and other resource management functions). Note that for fire management budget analysis purposes, the spacial pattern of fuel types is less important than the aggregate amount of area best represented by each type. The fire budget decision is sensitive to the overall fire hazard level but not to the detailed pattern of fires.

Funds invested in development of systems applicable to many national forests may be of greater value. For example, $3000 per year per forest multiplied by 70 forests implies a research budget for aggregate fuels inventory systems of roughly one-quarter of a million dollars per year. Such a value would be appropriate only if results found for other national forests are of the same order of magnitude as those found in this case study.

Fire Behavior/Fire Intensity

Information useful in refining estimates of fire behavior would generally take two forms: improved understanding of the physical processes involved and improved models to explicitly represent these processes. Research in these areas would presumably be applicable over regions or over the entire country, as opposed to a single forest level, which suggests that the cost of such research should be compared to the aggregate value of information over the country or a region.

The expected value of perfect information on fire behavior (specifically fireline intensity), given fuel load and weather conditions, was found for the Mt. Hood National Forest to be on the order of $20,000 annually.* It is likely the research leading to improved models and experimental calibration of such models would reduce uncertainty but not eliminate it. Comparison of the EVPI for the reduced uncertainty case with that for the nominal case suggests that the annual value to the Mt. Hood National Forest of such an improved capability would be in the range of $5,000 to $10,000. Aggregated over a region or over the entire USFS system, this gives an idea of the magnitude of USFS budget resources that might be allocated to such research.

Fire Management Effectiveness

The uncertainty in the relationship between budget-level and fire-management effectiveness is of a different nature from those uncertainties discussed previously and has to do as much with the performance of

*Assuming that the majority of budget decisions are of the incremental nature, as opposed to a major (i.e., +/- 50%) change.

personnel as with physical processes. The value of reducing such uncertainty would facilitate better decision making regarding fire management expenditures; the upper bound on the value of such information for the Mt. Hood is roughly $50,000 per year. Again, this is the expected value of perfect information. The resources that should be devoted to developing an improved understanding of fire management effectiveness are considerably lower that $50,000 but can be significant for USFS as a whole.

Section 4

FUEL TREATMENT DECISION

This section discusses an analysis of a site-specific decision: which fuel treatment alternative is appropriate after a timber harvest operation? The structure and detail of the problem being analyzed are based on a specific decision for a harvest site in the Mt. Hood National Forest. In addition, variations from the specific situation are made to give insight into a wider range of decisions of the same general type.

THE DECISION

The decision examined involves the choice of postharvest fuel treatment for a proposed 25-acre harvest. The site chosen for this analysis has characteristics which make the decision relatively complex (these characteristics are discussed later). Many fuel treatment decisions are much simpler in nature.

The Specific Site

The site under consideration consists of 25 acres of old growth Douglas fir with scattered white pine and hemlock in the Clackamas district of the Mt. Hood National Forest. Some understory growth is present, together with a significant quantity of timber litter. Fine fuels (less than 3 inches preharvest) are estimated to be on the order of one to two tons per acre.

The area is at an elevation of 3000, with a southwest aspect. The slope is concave at about 45%.

The proposed harvest is to be clear-cut, using a one-end suspended skyline system. All fir and hemlock are to be cut; the white pine will be left as seed trees. An important characteristic of the site is its remoteness: access is very poor.

In making the treatment decision, the fuels management staff faces several considerations:

- A considerable, though uncertain, quantity of activity fuels will be created during the harvest.
- It is desirable to reduce the quantity of these fuels to create planting sites, reduce fire hazard, and improve wildlife habitat.
- The poor access to the area makes treatment activities relatively expensive.
- It is important to retain the duff/humus layer in order to protect site quality.
- It is desirable to retain the white pine, which will serve as seed trees. Damage to or destruction of a significant portion of the white pine will greatly increase the costs of necessary hand planting.

Alternatives Considered

Three alternatives under consideration by Mt. Hood staff were evaluated, and further implications of some alternatives were investigated.

1. No Treatment. The no-treatment alternative actually involves a very minimal treatment, with spot treatment efforts by hand. The white pine is retained, but planting sites are of questionable quality, given the heavy load of activity fuels. The post-treatment fire hazard is

considerable. An important question involves the cumulative effects of selection of this alternative for a large number of sites. If the no-treatment alternative were selected for the majority of harvest sites, the amount of area in slash would increase. This might have implications on the overall level of fire hazard. The cost of the no-treatment alternative is, of course, very low--about $110 per acre.

2. Prescribed Burn. The burn alternative involves a coarse (8x10) yarding of unmerchantable material (YUM) followed by broadcast burning. It has the advantage of providing a considerable reduction in fuel load at an intermediate cost. This must be balanced with the uncertainty in the outcome of the burn. A burn that stays too cold will result in insufficient fuel reduction; if the burn becomes too hot, it may result in damage to the white pine or the duff/humus layer. There is also the possibility of the fire's escaping prescription, with attendant costs and damages. The remote location of the site under consideration gives this alternative an estimated cost of $800 per acre.

3. Intensive. The intensive treatment option involves YUM to a 6x6 level (removing all material greater than 6 inches by 6 feet). It has the advantage of eliminating risk to the white pine stands while providing significant reduction in fuel load. The cost of this is high--approximately $1300 per acre. Because of the uncertainty in fuel load and site conditions, it is not possible to predict precisely the cost of achieving a given level of fuel load after treatment. This uncertainty can be modeled in a number of ways. We have chosen to represent it by assuming that the treatment cost is fixed but that the

amount of post-treatment fuel loading is uncertain and determined by the pretreatment load.

Decision Structure and Data

A sequence of decisions is involved in determining the form of fuels treatment for a specific site. These decisions range from the initial decision regarding the harvest to the final choices made by the crew carrying out the prescribed treatment. Important uncertainties include the amount of preharvest (natural) fuels, the level of activity fuels created during the harvest, weather conditions prior to and during the treatment, and the effects of the chosen treatment alternative. Timber values are reasonably well known, but the relationships among silvicultural technique, treatment method, and future timber production are complex and uncertain. Values related to other resource uses, such as watershed and wildlife, are poorly defined. In the analysis discussed later in the section, a wide range of sensitivity analyses and various decision scenarios was used to investigate the implications of varying value assumptions and to provide insights into treatment decisions other than the specific case on the Mt. Hood National Forest.

The complexity of the situation is illustrated in Figure 4-1. Our discussion will emphasize the treatment alternative decisions, and the analysis will focus on the postharvest treatment decision. In practice, the fuels management staff devotes considerable effort to the analysis of treatment alternatives before the harvest is carried out. The tentative choice of treatment is used to calibrate treatment costs during bidding for

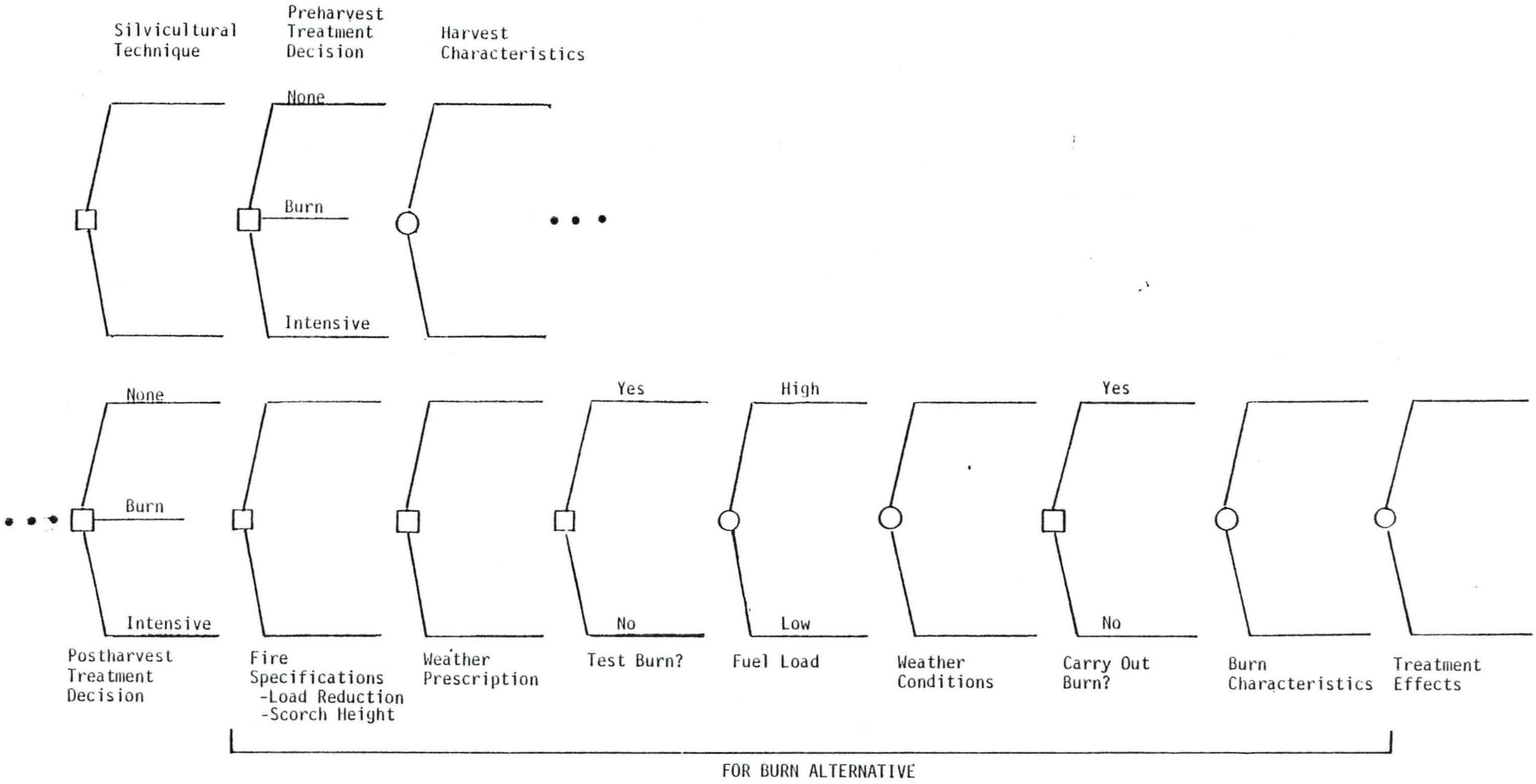


Figure 4-1

SEQUENCE OF HARVEST AND TREATMENT DECISIONS

the harvest site by timber industry groups. The costs of a "wrong" decision (e.g., one that is changed after more information is available after the harvest) are due to the procedural details of the USFS/timber industry relationship. It is difficult to collect funds in excess of those originally estimated to be necessary, and incentives exist to bias against refunds as well. Although the decision was complex, it was decided that the appropriate focus of this analysis was on the post- rather than the preharvest treatment decision, which allows for an emphasis on the physical processes and systems rather than organizational and financial procedures and regulations.

The decision tree in Figure 4-2 shows the postharvest treatment decision in greater detail. Implementing an analysis based on the structure of this decision required addressing several modeling and assessment issues.

Fuel Load Uncertainty. A critical uncertainty, both in analyzing the decision and determining the value of information, was in the quantity of fine fuels after harvest operations. Postharvest fine fuels (less than 3 inches) include both natural and activity fuels. The uncertainty in fuel load was assessed as follows. A Clackamas district fuels management specialist familiar with the site was shown a photo series representation of medium slash produced on a site similar to the one in question using a similar silviculture technique. The information provided by the photo series was assumed to be representative of that provided by a postharvest visual inspection of the site. Standard interview techniques [6,7] were

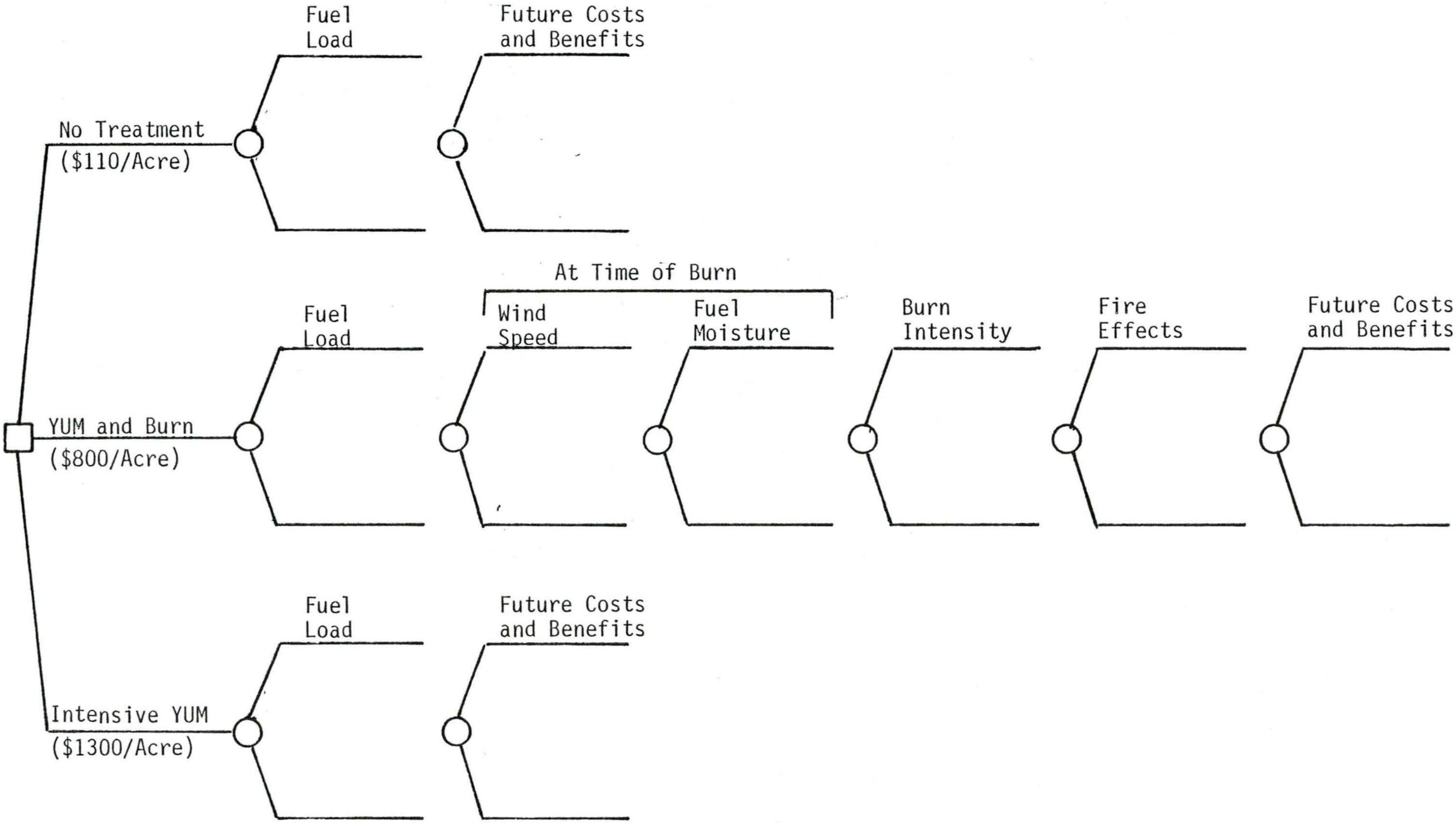


Figure 4-2

STRUCTURE OF POSTHARVEST FUEL TREATMENT DECISION

used to encode the subject's uncertainty on the quantity of fine fuels. The resulting cumulative probability distribution is shown in Figure 4-3.

The assessed distribution was approximated by a three-branch discrete probabililty distribution, as shown in Figure 4-4. This distribution was used in all subsequent analyses of the fuel treatment decision and provides the basis for calculation of the economic value of gathering more information on fuel load prior to making the postharvest treatment decision.

Fire Intensity. A second crucial uncertainty for the burn alternative is the fireline intensity of the burn. Modeling this uncertainty was carried out in three steps, the first two of which are described here and the third described in the following subsection.

The three steps involve:

1. Explicitly characterizing the uncertainties in fuel moisture, wind speed, and model predictions.
2. Combining the three uncertainties with the predicted fire intensities (given as a function of fuel load, fuel moisture, and wind speed) to produce cumulative probability distributions describing fire intensity given fuel load.
3. Combining the cumulative distributions on fire intensity with assessments of both acceptable intensity ranges and the ability of the burn crew to compensate for nonoptimal weather conditions to produce discrete probability distributions on the outcomes.

Predictions of fire intensity given wind speed and fuel moisture were provided by the Rocky Mountain Experiment Station using an existing fire behavior model [4,5]. An example of the output from this model is shown in Figure 4-5 for the case with a fine fuels load of 27 tons per acre. Uncertainty in the predicted intensity as a result of model and data approximations is represented in the top node of Figure 4-6.

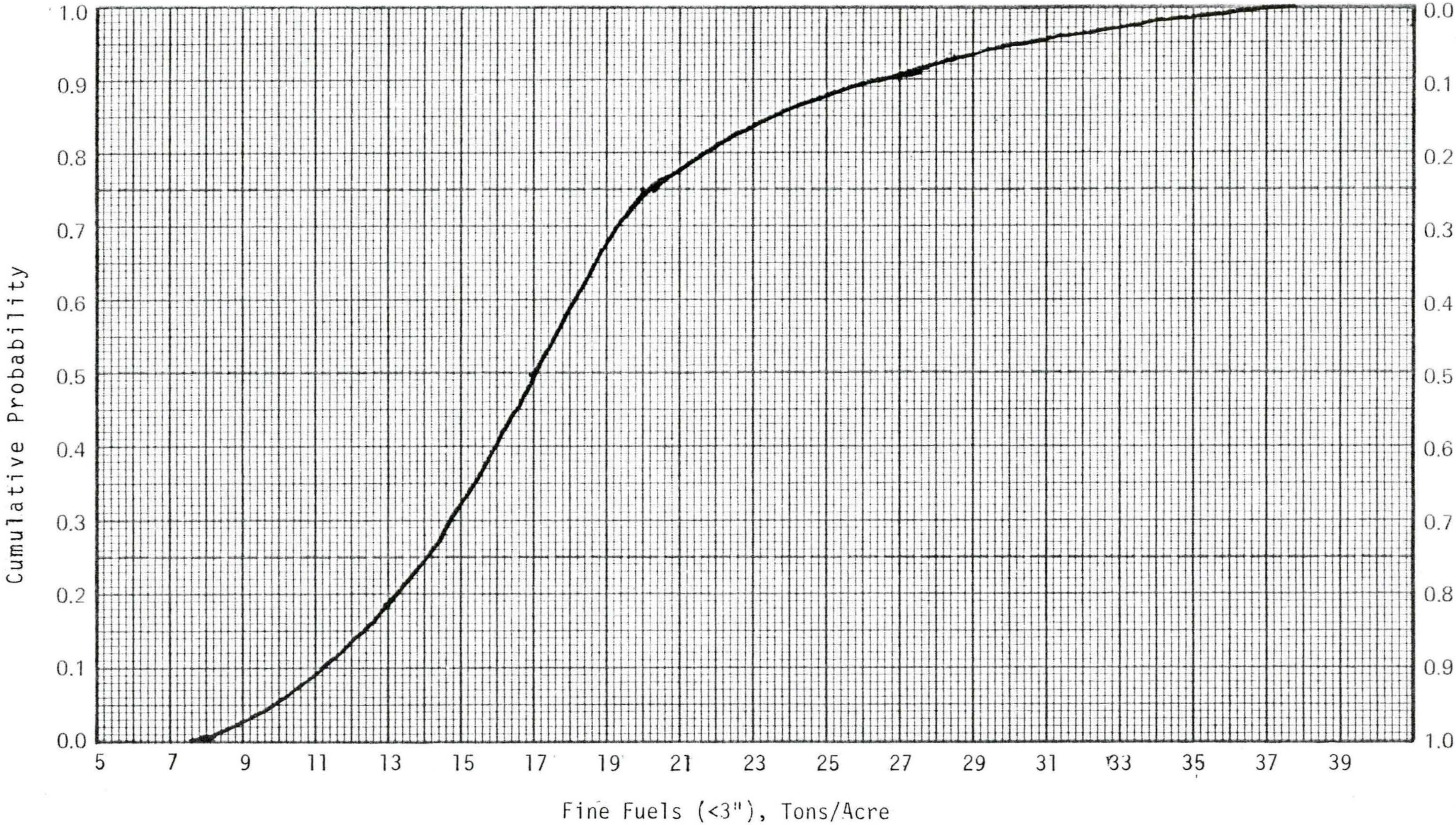


Figure 4-3
UNCERTAINTY IN POSTHARVEST
FUEL LOAD

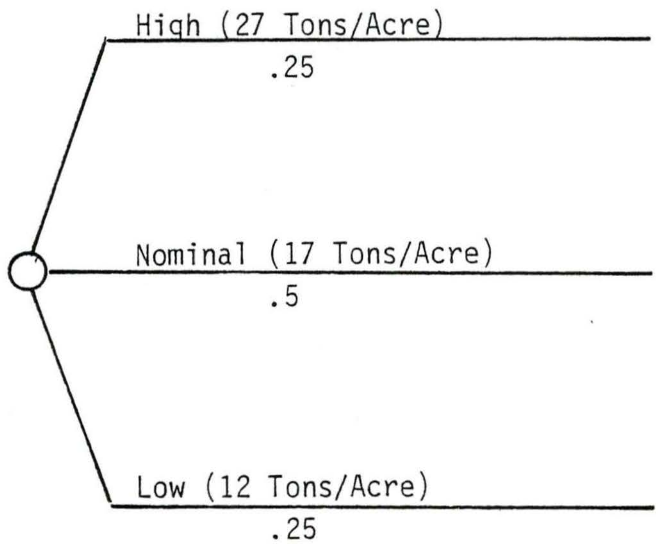


Figure 4-4
DISCRETIZED REPRESENTATION OF
UNCERTAINTY IN FUEL LOAD

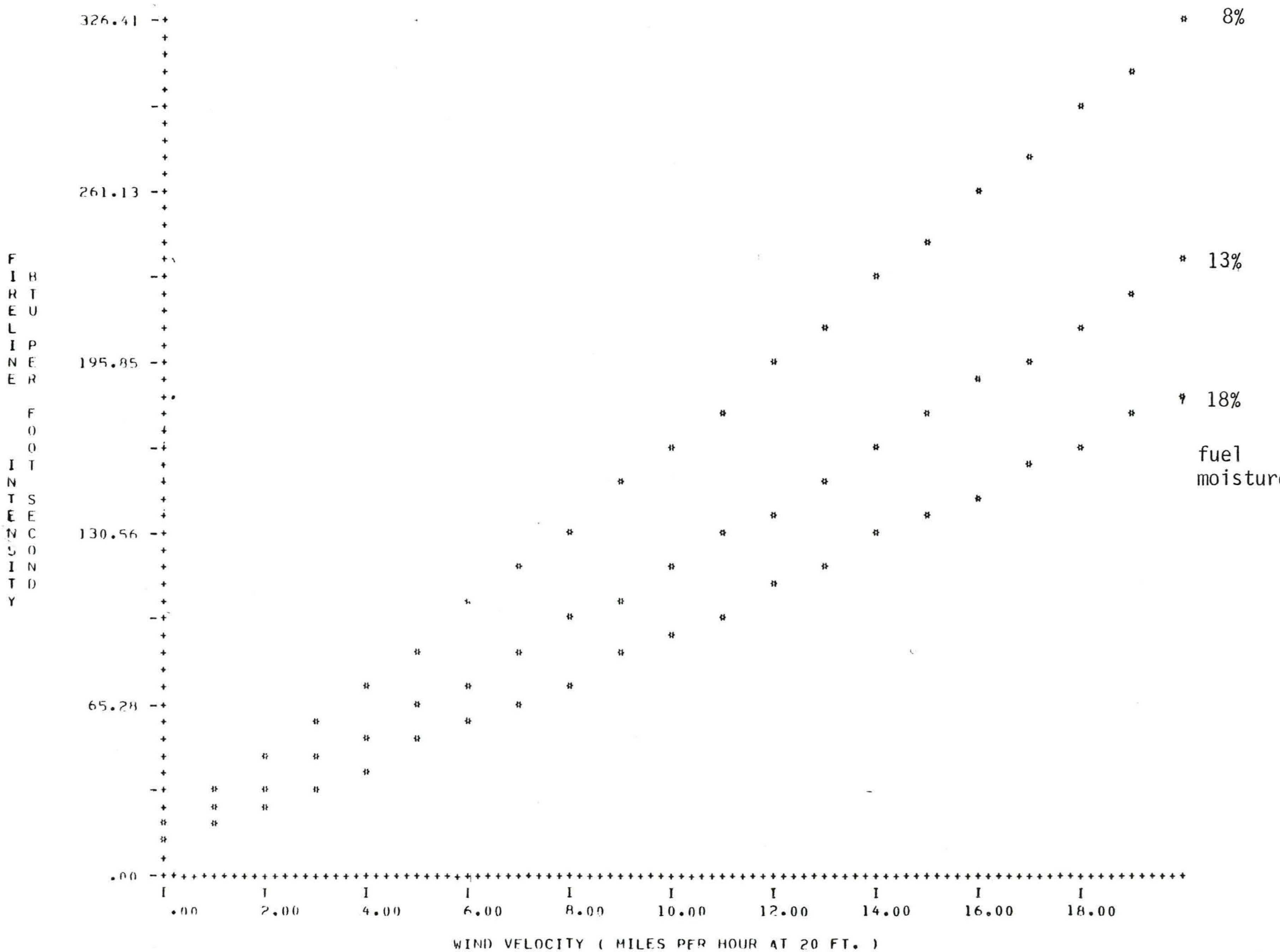


Figure 4-5
SAMPLE FIRE BEHAVIOR MODEL OUTPUT

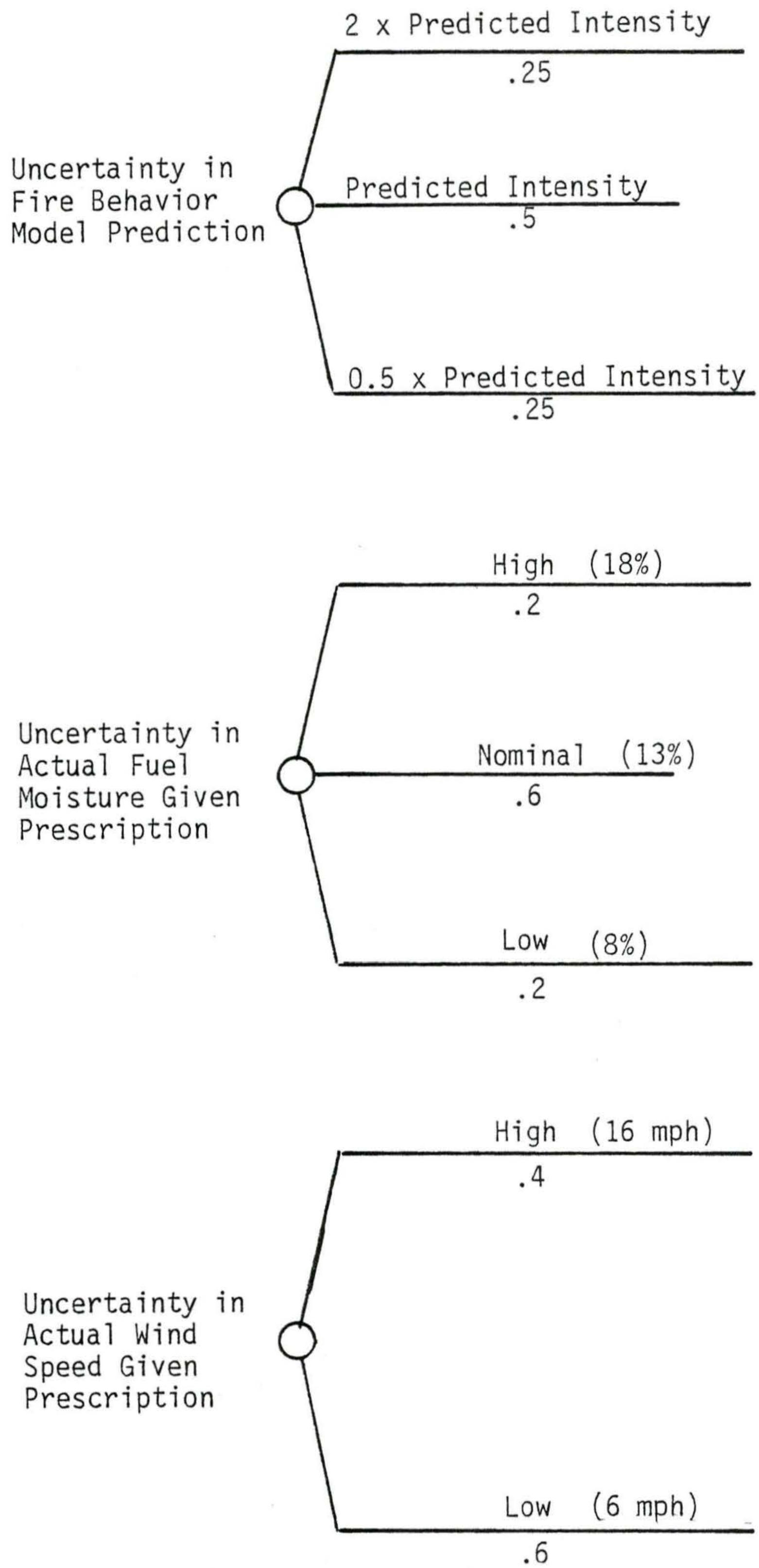


Figure 4-6

FACTORS INDUCING UNCERTAINTY IN FIRE INTENSITY

The weather prescription for a broadcast burn takes the form of a range of acceptable wind speed and fuel moisture conditions. The actual conditions at the time of burn are, within this range, uncertain from the perspective of the individual making the treatment method decision. The bottom two nodes in Figure 4-6 reflect the uncertainty likely to be present, based on the judgement of the Mt. Hood fuels specialist.

The uncertainties in model predictions, fuel moisture, and wind speed were factored together with the model output (an example of which is shown in Figure 4-5, given intensity as a function of wind and moisture) to produce cumulative probability distributions for intensity, given fuel load. Each combination of fuel load, model variation, wind speed, and fuel moisture resulted in an intensity figure and associated probability of occurrence. These intensities and probabilities were combined to give the three distributions shown in Figure 4-7, one for each separate fuel load level. The distributions shown thus reflect all three uncertain factors* shown in Figure 4-6.

Compensation Capability and Acceptable Intensity Range. The fire intensities just discussed leave out one important factor: the ability of treatment crews to compensate for wind and fuel moisture conditions by varying the ignition pattern and burn technique. The crews essentially have the capability to increase (to a limited extent) the intensity of a fire running too cold and to somewhat decrease the intensity of an overly hot fire. This capability is important in achieving the fuel reduction objectives while minimizing damage to the duff and white pine. The extent

*Assumed to be independent.

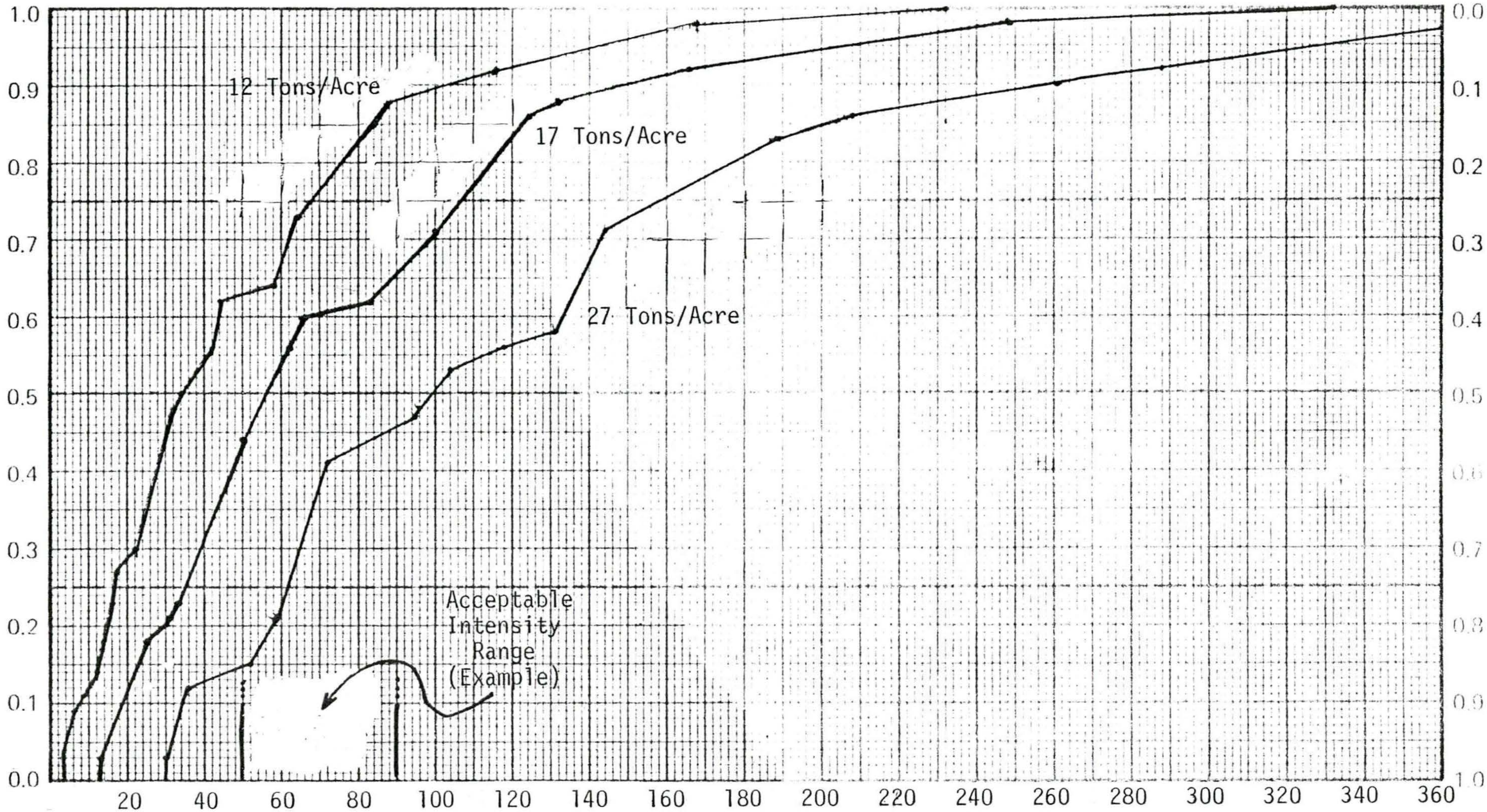


Figure 4-7
PREDICTED INTENSITY OF PRESCRIBED FIRE
GIVEN UNCERTAINTY IN WIND, FUEL MOISTURE, AND
FIRE BEHAVIOR PREDICTIONS, AND PRIOR TO BURN COMPENSATION.

of such capability is uncertain and applies to specific situations. Rather than trying to represent this uncertainty for the specific site, which would provide few insights for a broader class of treatment decisions, we have chosen to model the compensation (or control) capability together with the range of acceptable burn intensity to produce a set of decision scenarios.

This latter characteristic--the acceptable burn intensity--is an additional site-specific characteristic. A burn too cold will not achieve the desired reduction in fine fuels, but how cold a fire is acceptable depends on the site characteristics. In situations for which damage to duff or remaining overstory must be controlled, there is a threshold on the high-intensity side as well. The acceptable range can be approximated by an interval on the fireline intensity scale shown in Figure 4-7. A burn whose intensity falls within this range produces minimum post-treatment costs. Below the interval, the costs caused by the potential fire hazard of the remaining fuels increase. Above the acceptable range, the costs of damage to duff and, in the specific example, white pine, increase.* Thus, the burn alternative is modeled as having four possible outcomes: the three just mentioned plus the chance of the fire-escaping prescription.

Using the representation just discussed, the intensity control capability is represented by increasing the range of <u>predicted</u> (without compensation) intensity, which will result in the <u>actual</u> intensity's falling within the acceptable range. The four generalized decision

*This is a discrete-step approximation to a continuous relationship where effects are a function of intensity.

scenarios that were defined are summarized in Table 4-1(a). The correspondence between the four generalized decision scenarios and the various combinations of acceptable intensity ranges and control capabilities is shown in Table 4-1(b). What we have done essentially is to approximate a dozen specific scenarios through four generalized scenarios. Also shown for each combination is the actual estimated acceptable intensity range given compensation. Note that three specific combinations did not fall within any of the generalized scenario ranges listed in Table 4-1(a); these combinations were not analyzed further. The pattern is reasonable: greater control capability is equivalent to a wider range of acceptable fire intensities. The alternatives available are the same for each decision scenario: should a broadcast burn, an intensive treatment, or no treatment be selected?

Each decision scenario was applied to the three continuous probability distributions of Figure 4-7 to produce the discrete distributions shown in Table 4-2. The chance of a fire's escaping prescription is critical; to check this sensitivity, two modified scenarios (1a and 3a) incorporating a greater probability of escape were created from decision scenarios 1 and 3. Outcome distributions for these two scenarios are listed in Table 4-3.

<u>Costs and Benefits</u>. The approach taken in assigning costs and benefits was to assume that the objective of the treatment decision is to minimize the costs and losses that must be subtracted from a constant, nominal level of benefit. Three cost categories were defined: the cost of implementing the selected fuel treatment cost (decision cost), the post-treatment cost from the potential fire hazard (fire hazard cost), and the cost from damage

Table 4-1(a)

DECISION SCENARIOS

Scenario	Compensated Acceptable Intensity Range (Btu/ft/sec) Low End	High End
1	50-55	95-100
2	35-45	100-115
3	25-35	120-155
4	20-25	170-225

Table 4-1(b)

DECISION SCENARIOS

Control Capability	Acceptable Intensity Range* Wide (40-100 Btu/Ft/Sec)	Nominal (50-90 Btu/Ft/Sec)	Narrow (60-80 Btu/Ft/Sec)
Can Compensate For +/- 5 mph Wind Speed	DECISION SCENARIO 3 (33-120)	DECISION SCENARIO 2 (42-108)	DECISION SCENARIO 1 (50-96)
Can Compensate For +/- 10 mph Wind Speed	--- (16-250)	DECISION SCENARIO 4 (20-225)	DECISION SCENARIO 4 (24-200)
Can Compensate For +/- 5% Fuel Moisture	--- (25-140)	DECISION SCENARIO 3 (31-126)	DECISION SCENARIO 2 (38-112)
Can Compensate For +/- 5 mph Wind Speed and +/- 5% Fuel Moisture	DECISION SCENARIO 4 (21-170)	DECISION SCENARIO 3 (26-153)	DECISION SCENARIO 3 (32-136)
No Compensation Capability	DECISION SCENARIO 2 (40-100)	DECISION SCENARIO 1 (50-90)	--- (60-80)

* To minimize damage to remaining overstory

** BTU's/Ft/Sec

Table 4-2

PROBABILITY DISTRIBUTIONS ON OUTCOME OF PRESCRIBED BURN, GIVEN FUEL LOAD AND DECISION SCENARIO

Decision Scenario	Outcome	Fuel Load: Low	Fuel Load: Nominal	Fuel Load: High
1	Cold	.63	.44	.14
	Nominal	.27	.27	.33
	Hot	.10	.28	.46
	Escape	.00	.01	.07
2	Cold	.54	.31	.12
	Nominal	.37	.41	.38
	Hot	.09	.27	.43
	Escape	.00	.01	.07
3	Cold	.44	.20	.03
	Nominal	.51	.69	.61
	Hot	.05	.10	.29
	Escape	.00	.01	.07
4	Cold	.29	.11	.00
	Nominal	.70	.83	.79
	Hot	.01	.05	.14
	Escape	.00	.01	.07

Table 4-3

OUTCOME DISTRIBUTIONS FOR MODIFIED DECISION SCENARIOS

Decision Scenario	Outcome	Fuel Load Low	Fuel Load Nominal	Fuel Load High
1(a)	Cold	.62	.44	.14
	Nominal	.25	.25	.32
	Hot	.08	.26	.44
	Escape	.05	.05	.10
3(a)	Cold	.43	.20	.03
	Nominal	.49	.67	.60
	Hot	.03	.08	.27
	Escape	.05	.05	.10

to the white pine seed trees* (white pine cost). All costs are in terms of dollars for the 25-acre site.

Fire hazard costs were calculated using the annual cost-plus-loss model discussed in Section 3. Each fuel reduction outcome from the treatment decision (cold, nominal, hot, or escape for the burn alternative; low, nominal, or high fuel reduction for the 6x6 YUM alternative) was associated with a fire hazard class in the cost-plus-loss model. For the burn alternative, these hazards correspond roughly to J, K, and H fuel models. Output, given expected annual fire losses for each hazard class, was then scaled by the number of acres in the treatment site to give the annual expected fire losses for the site, given the treatment outcome. A twenty-year stream of the expected annual values was then discounted to the present value to produce the nominal fire hazard costs. A discount rate of 10% was used. The nominal values, along with sensitivity ranges, are shown at the top of Table 4-4. The costs of an escaped fire were similarly calculated by scaling the average cost of one such fire as calculated by the cost-plus-loss model.

White pine damage costs are based on the assumption that the greater the intensity of a prescribed burn, the greater the pine mortality, which implies less capability of the white pine to initiate regeneration of the site. This results in increased costs because of delay in regeneration and necessary hand planting, reseeding, and fertilizing. Costs used (shown in Table 4-4) are based on discussions with Clackamas district staff. The

*The white pine stands are analogous to any resource present in a treatment decision problem that suffers increasing damage as the intensity of the prescribed burn increases.

Table 4-4

COST COMPONENTS
(dollars/25 acres)

	Fire Hazard Cost		
Outcome	Low	Nominal	High
Cold (or Low Reduction)	500	1000	5000
Nominal	100	200	1000
Hot (or High Reduction)	50	100	500
Escape	15,000	30,000	75,000

	White Pine Damage Costs*		
Outcome	Low	Nominal	High
Cold	0	0	0
Nominal	1,500	3,000	15,000
Hot	7,500	15,000	75,000
Escape**	5,000	10,000	50,000

*White pine damage costs are zero for all outcomes of the no treatment or intensive treatment alternatives.

**White pine costs given the escape outcome are relatively low to avoid double counting with the fire hazard costs.

actual costs can vary from site to site. For this reason, a wide range of cost assumptions was examined in the value of information analysis discussed in the following paragraphs.

The decision costs were given on a per-acre basis. For the entire 25-acre site, the estimated costs of carrying out each alternative are as follows:

No Treatment	-	$ 2,500
YUM and Burn	-	$20,000
YUM 6x6	-	$32,500

Analysis Under Uncertainty. Analysis of the treatment decision produced a startling result: the no-treatment alternative was dominant, regardless of the decision scenario or cost assumption. This led to three possible conclusions:

1. There are benefits from fuel treatment considerably in excess of those explicitly quantified in this analysis.
2. Because of poor access, the costs of treatment for the studied site are much greater than for the average site.
3. Much more treatment activity is being carried out than is economically justified.

A hypothesis suggesting that conclusion 1 is the case is that the cumulative effect of choosing the no-treatment alternative on a regular basis would be to greatly increase the expected fire hazard. To test this hypothesis, we again used the cost-plus-loss model developed for the budget analysis. An extended period during which little fuel treatment was carried out would result in a considerably increased amount of area with a fire hazard represented by a slash type of stylized fuel model. This is reflected in the high slash case used in the budget level analysis. The

per-site fire hazard (expected annual loss) is increased significantly by the cumulative effects of no treatment: the costs almost double. However, the increase is not enough to lead to another alternative's being preferable.

Another possible explanatory factor is that significant benefits accrue to fuel treatment as a result of considerations other than fire hazard reduction and seed bed preparation. These might include, for example, watershed and wildlife values.

It is often the case that the no-treatment option is unacceptable because of silvicultural regulations: the site is required to be restocked within five years. This should properly be considered a site preparation decision rather than a fuel treatment decision.

The second possible conclusion is clearly true as far as it goes, but decreasing the costs of the treatment alternatives (say, by 50%) does not change the dominance of the no-treatment alternative. For one of the treatment alternatives to be optimal, all of the following must be true:

1. The cost of the treatment alternative must be lower by at least 50%.
2. The fire hazard costs must be at the high end of their range.
3. White pine damage costs (or other resources that may be damaged while carrying out fuel treatment) must be relatively low.

For the wide range of cases in which the no-treatment alternative is preferred, there is no value in reducing uncertainty in fuel load or in the outcomes of the other alternatives. For the purposes of the remainder of this analysis, it was assumed that some combination of conclusions 1 and 2 is descriptive of the situation. The no-treatment alternative was not considered further in the value of information analysis.

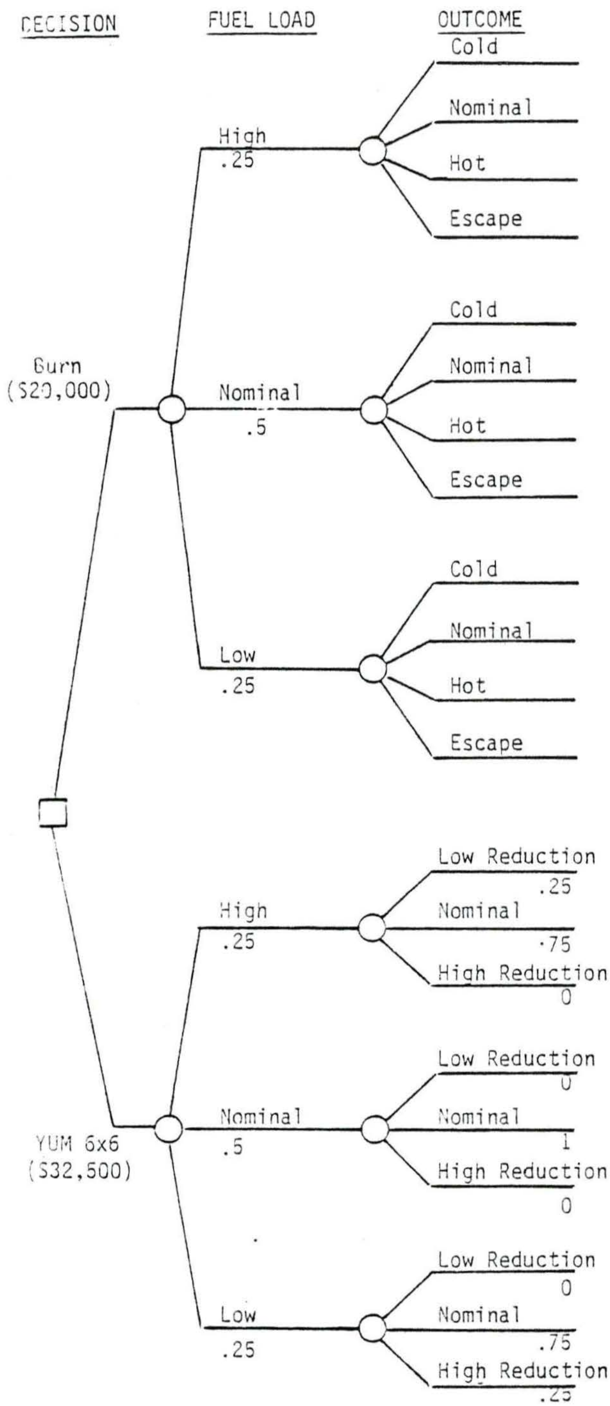
VALUE OF INFORMATION ANALYSIS

Figure 4-8 shows the decision tree on which the detailed analysis of the value of information was aased. Probabilities on the outcomes given the burn alternative depend on the decision scenario and are listed in tables 4-2 and 4-3.

Examination of the total cost column of Figure 4-8 highlights the difference between the two alternatives. The burn alternative is less expensive to carry out and may have a relatively low cost outcome, but it may also have a very costly outcome; the variance in its cost is relatively high. In contrast, the variance in the cost of the intensive treatment alternative (YUM 6x6) is extremely low, but the initial (and minimum) cost is considerably higher. One must balance the uncertainty in one case with the known higher costs in the other. This is a natural situation in which to explore the economic value of reductions in uncertainty.

For all six decision scenarios using nominal costs, the preferred alternative is the broadcast burn. As the white pine or fire hazard costs increase or the decision costs decrease, the optimal alternative shifts to the intensive YUM treatment. The point at which the decision under uncertainty shifts depends on the decision scenario.

The value of information analysis was carried out by calculating the EVPI on postharvest fuel load for each decision scenario while varying the fire hazard, white pine, and decision costs. Results of the analysis are summarized on the graphs in figures 4-9(a) through 4-9(d). In each figure, the EVPI on fuel load is plotted on the vertical axis, while the cost component being varied is plotted on the horizontal axis. Figures 4-9(a)



DECISION	FUEL LOAD	OUTCOME	FIRE HAZARD COST (Nominal)	WHITE PINE COST (Nominal)	TOTAL NOMINAL COST
Burn ($20,000)	High .25	Cold	1,000	0	21,000
		Nominal	200	3,000	23,200
		Hot	100	15,000	25,100
		Escape	30,000	10,000	60,000
	Nominal .5	Cold	1,000	0	21,000
		Nominal	200	3,000	23,200
		Hot	100	15,000	35,100
		Escape	30,000	10,000	60,000
	Low .25	Cold	1,000	0	21,000
		Nominal	200	3,000	23,200
		Hot	100	15,000	35,100
		Escape	30,000	10,000	60,000
YUM 6x6 ($32,500)	High .25	Low Reduction .25	1,000	0	33,500
		Nominal .75	200	0	32,700
		High Reduction 0	100	0	32,600
	Nominal .5	Low Reduction 0	1,000	0	33,500
		Nominal 1	200	0	32,700
		High Reduction 0	100	0	32,600
	Low .25	Low Reduction 0	1,000	0	33,500
		Nominal .75	200	0	32,700
		High Reduction .25	100	0	32,600

Figure 4-8
DECISION TREE FOR TREATMENT DECISION
VALUE OF INFORMATION ANALYSIS

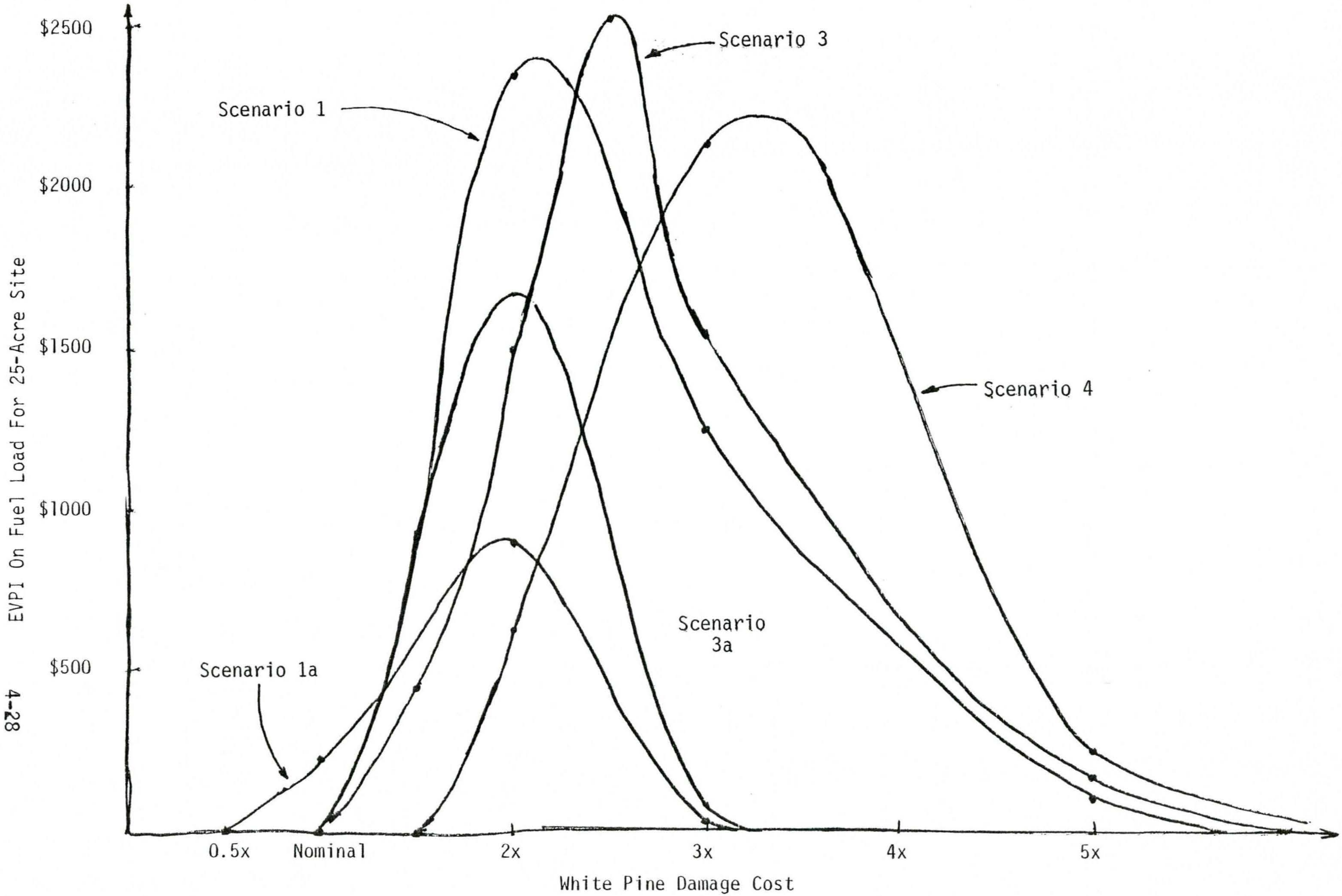


Figure 4-9(a)
EVPI ON FUEL LOAD, AS A FUNCTION OF WHITE PINE COST

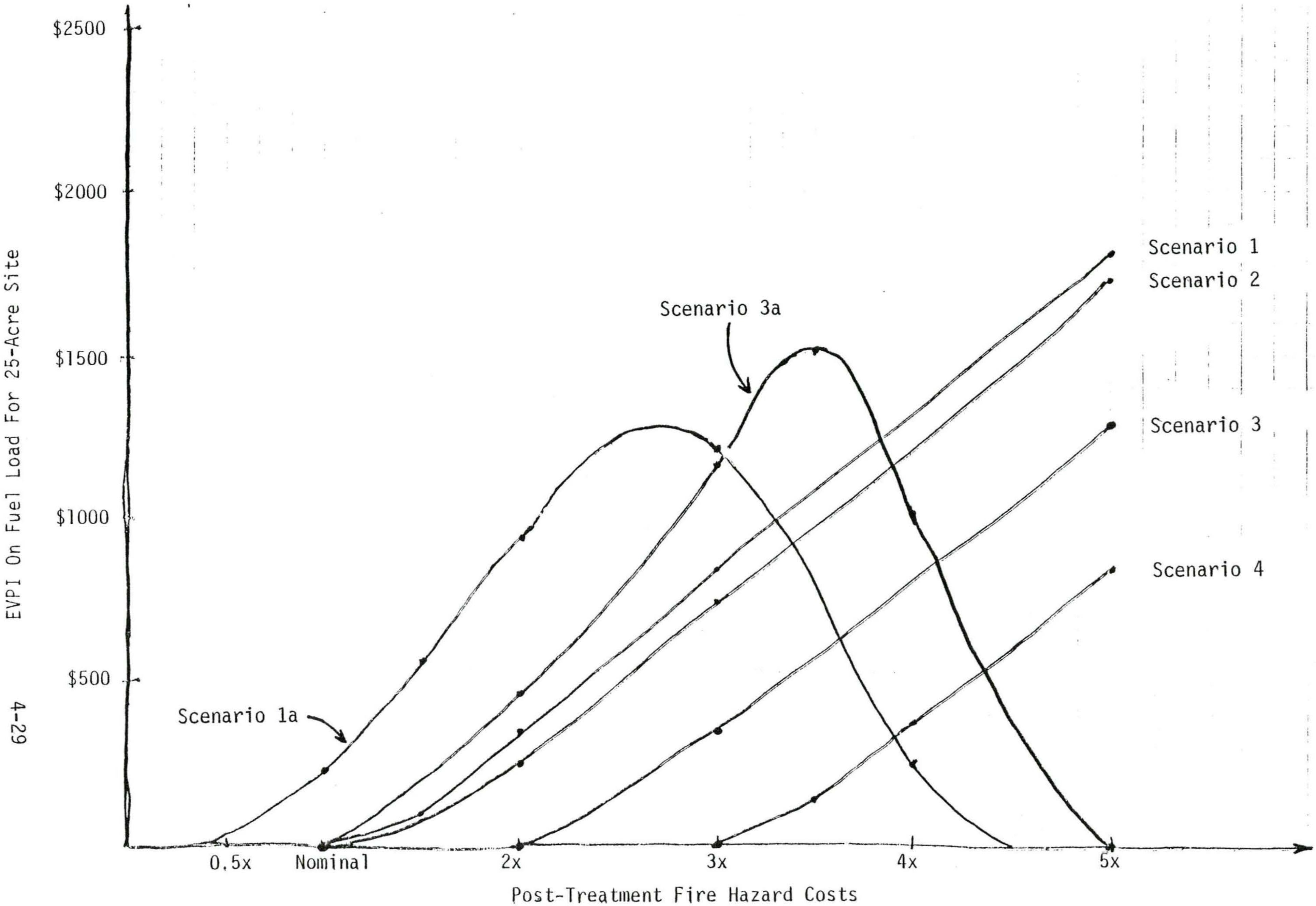


Figure 4-9(b)
EVPI ON FUEL LOAD, AS A FUNCTION OF FIRE HAZARD COST

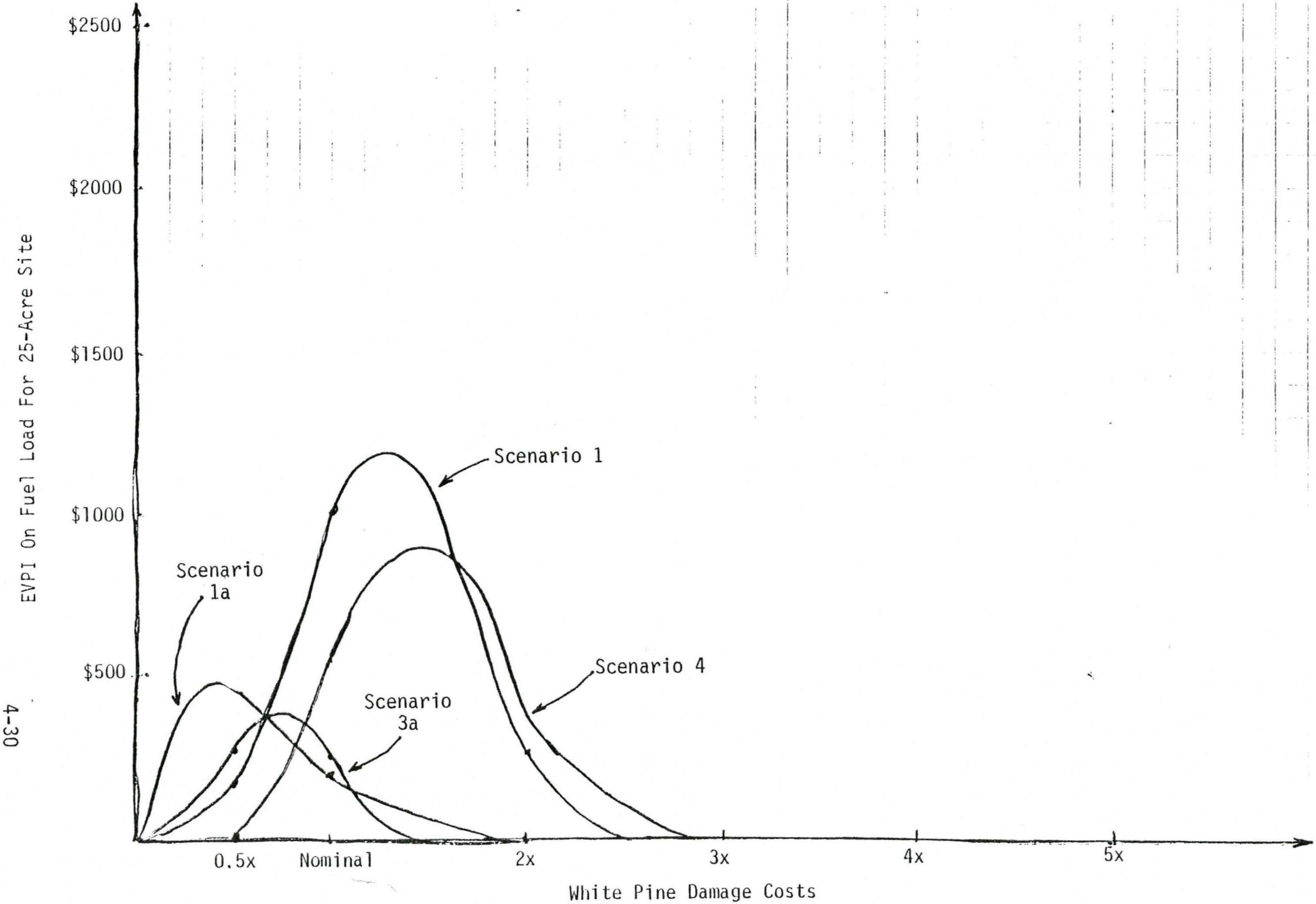


Figure 4-9(c)
EVPI ON FUEL LOAD, AS A FUNCTION OF WHITE PINE COST,
FOR SCENARIOS WITH ONE-HALF NOMINAL TREATMENT COSTS

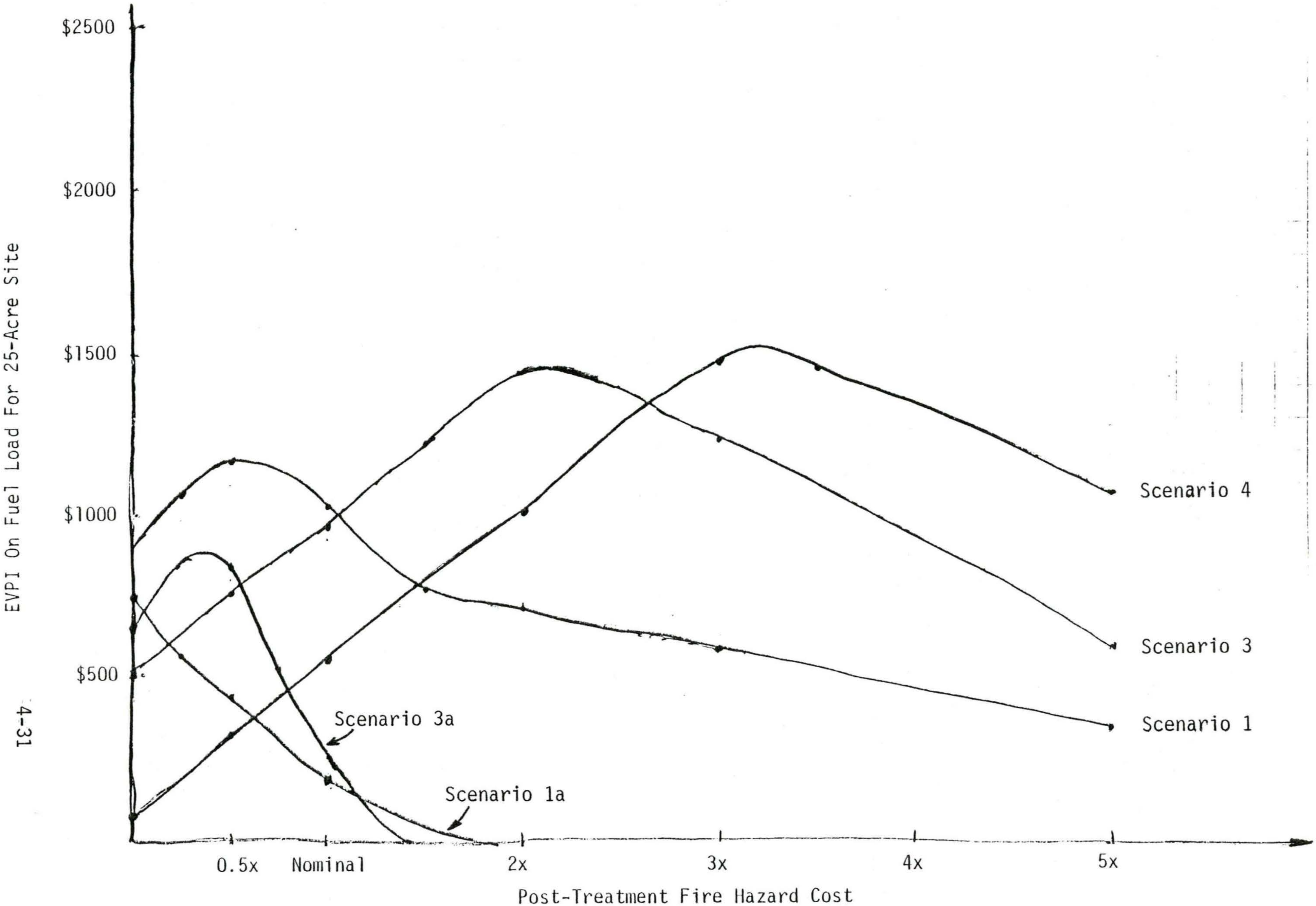


Figure 4-9(d)
EVPI ON FUEL LOAD, AS A FUNCTION OF FIRE
HAZARD COST, FOR SCENARIOS WITH ONE-HALF NOMINAL TREATMENT COSTS

and 4-9(b) assume costs of the treatment alternatives as defined for the specific site under study. Treatment costs that are lower by 50% are assumed in figures 4-9(c) and 4-9(d) and may more accurately reflect a majority of fuel treatment decisions (because of the increased cost resulting from poor access to the specific site examined).

Figure 4-9(a) shows how the EVPI on postharvest fuel load varies with decision scenario and white pine damage cost. The results for scenario 2 are similar to those for scenario 1. The general pattern reflects the dominance of the burn alternative when white pine costs are low and the dominance of the intensive treatment alternative when white pine costs are very high. For intermediate cost levels the choice is not clear, thus the EVPI is greatest. The EVPI is nonzero at nominal white pine damage costs only for decision scenario 1a, for which it is assumed that the acceptable intensity range is narrow, control capability is limited, and the probability of a fire's escaping prescription is relatively high. As one moves from scenario 1 through 3 to 4, note that the EVPI decreases for white pine costs in the range of nominal to twice nominal. This is due to the increasing robustness of the burn alternative as the acceptable intensity range and/or control capability increases. Finally, note that the cases with high escape probability (1a and 3a) have lower maximum EVPI values but have greater EVPI (than 1 and 3) at the lower (and more realistic) cost levels.

In Figure 4-9(b), the EVPI on fuel load is plotted against the post-treatment fire hazard costs. While the plots look considerably different, three patterns analogous to those of Figure 4-9(a) are found.

First, for all decision scenarios, the EVPI increases up to some point as the fire hazard cost component increases. Second, as the intensity tolerance assumed in the decision scenario increases (moving from 1 to 4), the EVPI on fuel load decreases for a given level of fire hazard cost. Finally, assuming relatively high probabilities of a fire's escaping prescription (scenarios 1a and 3a) leads to an increase in the EVPI at the lower (and again more realistic) levels of the cost components.

Figure 4-9(c) shows the variation in fuel load EVPI as white pine costs are changed for scenarios in which it is assumed that the costs of the treatment alternatives are one-half of the nominal (site-specific) values.* Scenarios 2 and 3 have plots similar to that for scenario 1. One immediately notices that both the maximum EVPI and the range of white pine cost over which the EVPI is nonzero are decreased from the nominal decision cost cases (Figure 4-9[a]). Of perhaps greater importance, the EVPI on fuel load for white pine damage costs of from one-half to one-and-one-half of nominal is considerably greater than was found for the nominal decision. At the nominal white pine damage cost level, EVPI on fuel load ranged from about $200 to $1000, depending on decision scenario. In this set of cases, with the costs of implementing the alternative treatment methods being perhaps closer to those found in a majority of treatment decisions, the scenarios with high probability of escaped fires have generally lower EVPI. This behavior reflects the dominance of the intensive treatment alternative when faced with such escape probabilities. More information would only rarely change the decision.

*Specifically, YUM and burn at $400 per acre or intensive 6x6 YUM at $600 per acre.

EVPI on fuel load as a function of fire hazard cost for the case will lower expected costs as shown in Figure 4-9(d). Again, scenario 2 is similar to scenario 1. It is interesting to contrast these plots with those for the nominal decision in Figure 4-9(b). The maximum EVPI is achieved at much lower assignments of fire hazard cost for each decision scenario. In particular, the value of perfect information at the nominal fire hazard cost point is significant, ranging from $500 to $1000 for the basic scenarios. The modified scenarios (with higher probability of a fire's escaping prescription) result in generally lower EVPI values, reflecting the dominance of the low-variance intensive treatment option for such scenarios. In comparison with Figure 4-9(c), one notes that the EVPI is relatively high for a wide range of hazard costs in Figure 4-9(d). Fire hazard cost is a major outcome regardless of the alternative chosen, while white pine damage is risked only for the burn alternative.

THE VALUE OF IMPERFECT INFORMATION

The information values discussed above represent the expected values of perfect information. Equivalently, the EVPI gives the economic value of totally eliminating the uncertainty inherent in the state of information of the fuels management specialist. Clearly, such a complete elimination of uncertainty is impossible (or at least very expensive) in the context of postharvest loading of fine fuels.

To investigate the value of reducing but not eliminating uncertainty, we calculated the EVPI on fuel load for a variety of cases in which the variance in the initial probability distributed was reduced by about 60%. This led to EVPI values in the range of 30-50% of those plotted in figures

4-9(a) through 4-9(d). The variation in EVPI with respect to the decision scenarios and cost components was analogous to the original cases.

This analysis suggests that the value of improved but not perfect information might be on the order of one-half to two-thirds of the EVPI. Such reduced information values are most appropriate for use in guiding the allocation of information-gathering resources.

SUMMARY AND RECOMMENDATIONS

For the site-specific decision as originally defined, the no-treatment alternative was clearly dominant. When the costs of treatment are cut in half to levels that more closely approximate many treatment decisions, the no-treatment alternative is still preferable. For the reduced treatment cost decision problem, decreasing fire hazard or white pine damage costs could lead to one of the treatment options being superior.

In light of the above observations, we suggest that more research is necessary to either:

1. Determine the cumulative fire hazard cost, wildlife benefits, or other factors that justify carrying out fuels treatment activities on a majority of harvest sites, or
2. Demonstrate that the values defined in (1) are insufficient to justify on an economic basis the amount of fuel treatment activity presently being done.

In treatment decisions for which the no-treatment alternative is not dominant (or when it has been decided that some treatment is necessary, based on other factors), some effort devoted to gathering information on postharvest fuel load may be worthwhile. Using the most likely scenarios,

the expected value of perfect information on fuel load was approximately $300 to $800 for a 25-acre site. Information that could be expected to reduce uncertainty (perhaps reducing the variance of the probability distribution on the loading of fine fuels by 50-75%) would be worth $100 to $400. Accounting for all costs, this suggests that in many cases it would be worthwhile to invest one or two person-days in developing an improved estimate of postharvest fuel load <u>before</u> making the final treatment decision.

It is worth noting that improved information could have value beyond reducing uncertainty in the aggregate mass of fine fuels. Better understanding of the breakdown of fuels by size and type could be used as input to an improved fire behavior model to obtain better predictions of the characteristics of prescribed fires. The same information would also be of assistance in carrying out the treatment option ultimately selected and in assessing the effectiveness of treatment.

Our recommendations can be summarized as follows:

- Careful thought should be given as to whether the no-treatment alternative might be appropriate in more instances. Improved exchange of information among fuels management, silviculture, wildlife, recreation, and other specialists would help in resolving this issue.

- For harvest sites having important resources that are sensitive to damage from a burn or for sites having poor access leading to high treatment costs, the more expensive hand treatment options may be worthwhile (assuming any treatment is justified).

- For the many cases in which broadcast burning is likely to be a good alternative but for which some resource values may be sensitive to over- or underburning, it is probably worth investing on the order of one person-day in improving the information base prior to making the final treatment decision.

Section 5

REFERENCES

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[2] Ronald A. Howard. "Information Value Theory." IEEE Transactions on Systems Science and Cybernetics. SSC-2, No. 1, August 1966.

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[5] Frank A. Albini. Estimating Wildfire Behavior and Effects. Intermountain Forest and Range Experiment Station General Technical Report INT-30, 1976.

[6] Carl Spetzler and C. A. S. Stael von Holstein. "Probability Encoding in Decision Analysis." Management Science, 22, November 1975.

[7] C. A. S. Stael von Holstein. Assessment and Evaluation of Subjective Probability Distributions. Stockholm: The Economic Research Institute at the Stockholm School of Economics, 1970.

Appendix A

BASE CASE AND SENSITIVITY DATA

GENERAL

Data represent the Clackamas and Estacada districts of the Mt. Hood National Forest.

NOMINAL BUDGET

(dollars per year)

Prevention	$ 58,000
Presuppression and Initial Attack	208,000
Fuel Treatment and Brush Disposal	477,000
Total	743,000

IGNITIONS

(average number per year)

Industrial	1
Other Human-Caused	25
Lightning	8

NOMINAL AREA DISTRIBUTION: FUEL TYPES

Total Area	400,000	acres
Timber Litter Plus Understory (G)	280,000	
Timber Litter (H)	80,000	
Heavy Slash (I)	20,000	
Medium Slash (J)	20,000	

INTENSITY DISTRIBUTION

The following table gives the discretized probability distributions for fireline intensity (Btu/ft/sec), given the fuel model type in which a fire starts. These data are based on the cumulative probability distributions generated by the Rothermal/Albini fire behavior model using weather data for the case study area. (A sample model run is shown as Figure A-1.)

Area Type of Fire Start	Intensity Class		
	Low (0-100)	Moderate (100-700)	High (>700)
Heavy Slash (I)	0.000	0.280	0.720
Medium Slash (J)	0.030	0.610	0.360
Timber Litter (H)	1.000	0.000	0.000
Litter + Understory (G)	0.780	0.190	0.030

ESCAPE FRACTIONS

The following table gives the fraction of fires escaping initial attack (or, equivalently, the probability that a fire escapes) as a function of fuel model type and intensity class. The fraction of fires in each category that are controlled during initial attack is one minus the appropriate table entry. The escape fractions are based on the judgement of Mt. Hood fuels and fire management staff.

Area Type of Fire Start	Intensity Class		
	Low (0-100)	Moderate (100-700)	High (>700)
Heavy Slash (I)	0.0	0.3	0.8
Medium Slash (J)	0.0	0.3	0.8
Timber Litter (H)	0.0	0.3	0.8
Litter + Understory (G)	0.0	0.3	0.8

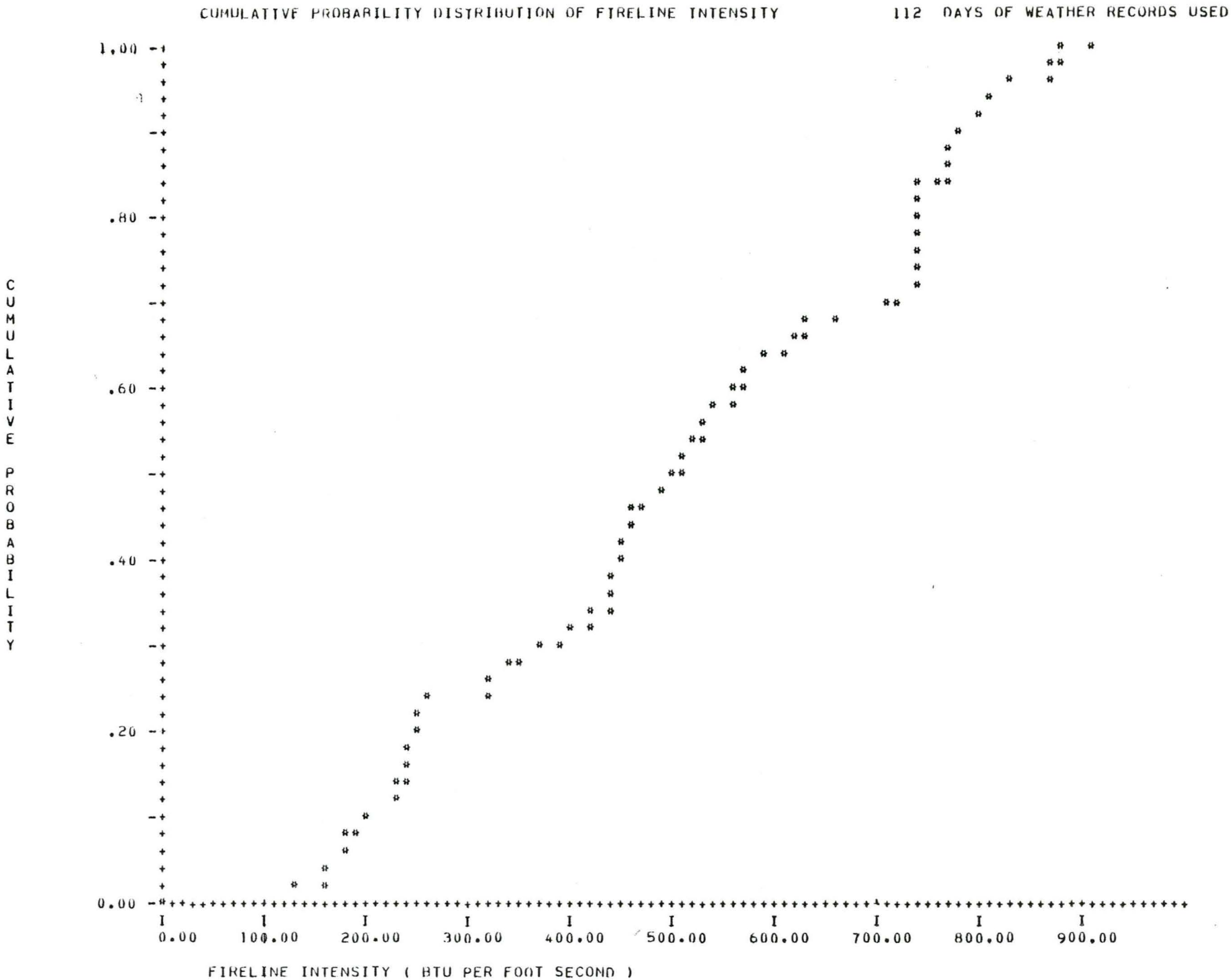

Figure A-1
SAMPLE FIREBEHAV OUTPUT (FUEL MODEL NFFL I, WEATHER STATION 350707)

SIZE DISTRIBUTION

The following tables give the individual probability distributions for fire size class, given area type (stylized fuel model type) of fire start and intensity class. Two sets of tables are used: one for fires controlled in initial attack and one for escaped fires. One table in each set is given for each area type. The distributions are based on the judgement of Mt. Hood fuels and fire management staff. An iterative process was used whereby the implications of an initial set of distributions were used to refine the assessments.

Controlled Fires

Area Type: Heavy Slash (I)

Intensity Class		Size Class 0.1 Ave. Acres	10 Ave. Acres	100 Ave. Acres	1000 Ave. Acres
Low	(0-100)	0.95	0.05	0.00	0.00
Moderate	(100-700)	0.80	0.20	0.00	0.00
High	(>700)	0.60	0.40	0.00	0.00

Area Type: Medium Slash (J)

Intensity Class		Size Class 0.1 Ave. Acres	10 Ave. Acres	100 Ave. Acres	1000 Ave. Acres
Low	(0-100)	0.95	0.05	0.00	0.00
Moderate	(100-700)	0.80	0.20	0.00	0.00
High	(>700)	0.60	0.40	0.00	0.00

Area Type: Timber Litter (H)

Intensity Class		Size Class: 0.1 Ave. Acres	10 Ave. Acres	100 Ave. Acres	1000 Ave. Acres
Low	(0-100)	0.95	0.05	0.00	0.00
Moderate	(100-700)	0.80	0.20	0.00	0.00
High	(>700)	0.60	0.40	0.00	0.00

Area Type: Litter + Understory (G)

Intensity Class		Size Class: 0.1 Ave. Acres	10 Ave. Acres	100 Ave. Acres	1000 Ave. Acres
Low	(0-100)	0.95	0.05	0.00	0.00
Moderate	(100-700)	0.80	0.20	0.00	0.00
High	(>700)	0.60	0.40	0.00	0.00

Escaped Fires

Area Type: Heavy Slash(I)

Intensity Class		Size Class: 0.1 Ave. Acres	10 Ave. Acres	100 Ave. Acres	1000 Ave. Acres
Low	(0-100)	0.20	0.80	0.00	0.00
Moderate	(100-700)	0.10	0.70	0.19	0.01
High	(>700)	0.00	0.80	0.18	0.02

Area Type: Medium Slash (J)

Intensity Class		Size Class: 0.1 Ave. Acres	10 Ave. Acres	100 Ave. Acres	1000 Ave. Acres
Low	(0-100)	0.40	0.60	0.00	0.00
Moderate	(100-700)	0.20	0.60	0.19	0.01
High	(>700)	0.00	0.80	0.18	0.02

Area Type: Timber Litter (H)

Intensity Class		Size Class: 0.1 Ave. Acres	10 Ave. Acres	100 Ave. Acres	1000 Ave. Acres
Low	(0-100)	1.00	0.00	0.00	0.00
Moderate	(100-700)	0.20	0.60	0.20	0.00
High	(>700)	0.00	0.80	0.19	0.01

Area Type: Litter + Understory (G)

Intensity Class		Size Class: 0.1 Ave. Acres	10 Ave. Acres	100 Ave. Acres	1000 Ave. Acres
Low	(0-100)	1.00	0.00	0.00	0.00
Moderate	(100-700)	0.20	0.60	0.19	0.01
High	(>700)	0.00	0.80	0.18	0.02

FIRE DAMAGE COSTS

Fire damage costs, or losses, are listed in the following set of tables. Losses are in terms of dollars per acre per fire. Values given are based primarily on damage to timber resources and cost of rehabilitation; implications of assigning greater values based on non-market-traded resources are examined in the sensitivity analysis and value of information subsections. Timber values and rehabilitation costs used are based on recent experience in the Mt. Hood National Forest.

Losses are a function of fire size, intensity, and location. Fires in the lowest intensity range have very low timber damage costs. Small fires starting in slash are also assigned small losses, as such fires damage little timber. Larger fires starting in slash areas are expected to have spread into timber, implying greater timber damage cost.

Area Type: Heavy Slash(I)

Intensity Class		0.1 Ave. Acres	10 Ave. Acres	100 Ave. Acres	1000 Ave. Acres
		Size Class			
Low	(0-100)	200	200	200	200
Moderate	(100-700)	500	500	1000	1000
High	(>700)	500	750	1200	1200

Area Type: Medium Slash (J)

Intensity Class		0.1 Ave. Acres	10 Ave. Acres	100 Ave. Acres	1000 Ave. Acres
		Size Class			
Low	(0-100)	200	200	200	200
Moderate	(100-700)	500	500	1000	1000
High	(>700)	500	750	1200	1200

Area Type: Timber Litter (H)

Intensity Class		0.1 Ave. Acres	10 Ave. Acres	100 Ave. Acres	1000 Ave. Acres
		Size Class			
Low	(0-100)	200	200	200	200
Moderate	(100-700)	1000	1500	1500	1200
High	(>700)	1500	2000	2000	2000

Area Type: Litter + Understory (G)

Intensity Class		0.1 Ave. Acres	10 Ave. Acres	100 Ave. Acres	1000 Ave. Acres
		Size Class			
Low	(0-100)	200	200	200	200
Moderate	(100-700)	1000	1500	1500	1200
High	(>700)	1500	2000	2000	2000

SUPPRESSION COSTS

Suppression costs for fires escaping initial attack are shown in the following table. These costs are based on experience in the Mt. Hood and other Region Six forests. It is assumed that all fires of the smallest size class are controlled in initial attack. Costs are given in average dollars per acre per fire.

		Size Class			
Intensity Class		0.1 Ave. Acres	10 Ave. Acres	100 Ave. Acres	1000 Ave. Acres
Low	(0-100)	0	500	500	500
Moderate	(100-700)	0	500	500	500
High	(>700)	0	500	500	500

SENSITIVITY TEST DATA

Area Type Distributions: (thousands of acres)

	Fuel Model Type			
Case	I	J	G	H
High Slash	40	80	200	80
Nominal	20	20	280	80
Low Slash	10	10	280	100

Intensity Distribution with Two Times Intensities

	Intensity Class		
Area Type of Fire Start	Low (0-100)	Moderate (100-700)	High (>700)
Heavy Slash (I)	0.050	0.410	0.540
Medium Slash (J)	0.130	0.600	0.270
Timber Slash (H)	1.000	0.000	0.000
Litter + Understory (G)	0.810	0.170	0.020

Intensity Distribution with One-Half Times Intensities

Area Type of Fire Start	Intensity Class Low (0-100)	 Moderate (100-700)	 High (>700)
Heavy Slash (I)	0.000	0.140	0.860
Medium Slash (J)	0.010	0.480	0.510
Timber Slash (H)	0.500	0.500	0.000
Litter + Understory (G)	0.390	0.480	0.130

Appendix B

THE ROLE OF FUELS INFORMATION IN PREDISPATCH (INITIAL ATTACK) PLANNING DECISIONS

During our initial interviews on the Mt. Hood National Forest, we concluded that improved fuels information would have very little impact on predispatch planning decisions, and therefore the value of area-wide information would be low in the context of these decisions. This appendix explains the basis for that conclusion.

The term "predispatch planning" refers to the prescription of initial attack forces (workers and equipment) on an area-by-area basis. The Mt. Hood National Forest is divided into about 100 predispatch blocks of about 40 square miles each. A dispatch card is on file for each block and fire condition. When a fire occurs on the Mt. Hood, weather and location are noted and the appropriate card is consulted by the dispatcher to determine the preplanned initial attack strategy; control forces are dispatched accordingly. The level of initial attack can range from a handful of workers in a single vehicle to several trucks, helicopters, and air tankers. Predispatch planning is based on estimates of block-by-block fire behavior which in turn depend on estimates of fuel conditions.

A hypothetical situation was posited to the Mt. Hood managers responsible for the predispatch planning in order to assess the possible impact of better fuels information on their initial attack decisions. The managers were asked to suppose that a fuel clairvoyant were available who

could tell them anything they wanted to know about fuel conditions on the Mt. Hood National Forest. They were then asked to designate the predispatch blocks for which they would seek the clairvoyant's information, because it might cause them to change their current initial attack prescriptions. The surprising response was that they thought the clairvoyant's services would be of value on only 5-8% of the predispatch blocks. The exact blocks were noted on a map. Within these blocks it was not clear whether fuels information in and of itself would reduce their uncertainty about fire behavior. This led us to conclude that better fuels information would probably not significantly reduce costs associated with initial attack decisions.